CR-137691

FEASIBILITY STUDY OF MODERN AIRSHIPS

FINAL REPORT

Phase I

Volume I

Prepared under Contract Number NAS2-8693

for

National Aeronautics and Space Administration
Ames Research Center

by

BOEING VERTOL COMPANY
A DIVISION OF THE BOEING COMPANY
PHILADELPHIA, PENNSYLVANIA

D210-10953-1

May 1975

ERRATA SHEET

Page i:

The two top lines read:	Should read:
"Abstract i	"Abstract xiii
Foreword . . . . ii"	Foreword . . . . xv"

Page xv:

The six last lines in the fourth paragraph should read: (the following can be cut out and pasted in place).

Capt. (N) Fred Berry (Ret.) of the Quest Research Corporation, McLean, Virginia, for the support in the historical phase by giving access to rare documents on the 1930's airship operation, collected by his father, Cdr. F. Berry, Commanding Officer of the Naval Air Station, Lakehurst, N.J., who was one of the victims in the Akron accident on 4 April 1933.

Photographs in the following figures are credited to:

1. "The Airships Akron and Macon", by Richard K. Smith. Copyright (c), 1965, United States Naval Institute. Figures 3-12, 3-14, 3-15, 3-16, 3-17 and 3-28.
2. Official Navy Photographer at the Naval Air Station, Lakehurst, N.J., Figure 3-11 and 3-33.
3. Raven Industries, Inc., Figure 4-2.

Page 1-2:

on line 11 from top

reads:	should read:
"(Appendix C)"	"(Volume II)"

Page 5-22:

In Figure 5-19 and on third line from bottom:

reads:	should read:
"Sterling"	"Stirling"

Page 6-8:

In line under the table

reads:	should read:
"(272,000 kg)"	"(2,721,600 kg)"

CR-137691 (1)

FEASIBILITY STUDY OF MODERN AIRSHIPS

FINAL REPORT

PHASE I

VOLUME I

Prepared under Contract Number NAS2-8693

for

National Aeronautics and Space Administration
Ames Research Center

by

B. Joner
D. Grant
H. Rosenstein
J. Schneider

BOEING VERTOL COMPANY
A DIVISION OF THE BOEING COMPANY
PHILADELPHIA, PENNSYLVANIA

D210-10953-1

May 1975

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

ABSTRACT

The history of the airship is examined from a technical and operational/mission point of view. The impact on a modern airship design by present technology is defined in some selected, representative areas through a comparison between 1930 and 1975 state-of-the-art.

A survey of missions with a potential for the airship is made and some viable applications are established.

Several concepts of modern airships are taken through a parametric design analysis in the missions previously established, evolving in a new configuration of a hybrid airship - the Helipsoid -, combining static lift and dynamic lift from tilting propeller/rotors and the planform. Cruise speeds in the 150-200 kt (77-103 m/s) will be possible with this configuration with reasonable engine power. The Helipsoid offers at the same time a realistic and practicable solution to the ballast problem, which is inherent in a vehicle generating its lift (fully or partially) from a medium lighter than air.

FOREWORD

This report presents the results of Phase I of a Feasibility Study of Modern Airships performed under NASA Ames Contract No. NAS2-8693 by the Boeing Vertol Company.

Dr. Mark Ardema of NASA Ames Systems Study Division was technical monitor of the program. The Boeing Vertol program manager for the study was Mr. Bruno Joner. Prime contributors have been Messrs. John Davis, David Grant, Milton Gerstine, David Pritchard, Harold Rosenstein, John Schneider, Richard Semple, Robert Shannon, and Archibald Sherbert, who all, including many more not mentioned, have devoted their interest and effort to the reevaluation of the Lighter-Than-Air concept.

Valuable assistance on lighter-than-air technology by Dr. Robert Ross, consultant to NASA Ames on the LTA feasibility study, is acknowledged with thanks.

A grateful acknowledgement is expressed to Mr. Lawrence Greene of the Department of Transportation for furnishing requirements for potential U.S. Coast Guard missions for airships, Mr. Carmen Mazza of the Naval Air Development Center (NADC) for furnishing information on potential U.S. Navy missions, and Lt. Col. Buel Wolverton, U.S. Air Force Space and Missile Systems Organization (SAMSO) for furnishing information on potential U.S. Air Force missions for an airship. Recognition and thanks is further expressed to Capt. (N) Fred Berry (Ret.)
McLean, Virginia, for the support in the historical phase by giving access to rare documents on the 1930's airship operation, collected by his father, Cdr. F. Berry, Commanding Officer of the Naval Air Station, Lakehurst, N.J., 4 April 1933.

Photographs in the following figures are credited to:

1. "The Airships Akron and Macon", by Richard K. Smith. Copyright (c), 1965, United States Naval Institute. Figures 3-12, 3-14, 3-15, 3-16, 3-17 and 3-28.
2. Official Navy Photographer at the Naval Air Station, Lakehurst, N.J., Figure 3-11 and 3-33.
3. Raven Industries, Inc., Figure 4-2.

1. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1.1 Summary

During the early 1930's, the rigid airship was the Queen of the Skies. The design, manufacturing, and operational techniques and the facilities had been developed over a 30-year span to the point where the airship easily exceeded contemporary airplanes in range and payload, and even productivity as well. Through a combination of circumstances, failures, and political expediencies, development of the rigid airship was terminated while development of the airplane and its propulsion systems accelerated at a tremendous pace.

There has been a number of attempts throughout the world in recent years to initiate airship development. The need for reduced energy usage and lowering of pollution, coupled with the need for transporting large, heavy, indivisible loads, do appear on the surface to be satisfied by the unique characteristics of the airship. The study reported herein presents an up-to-date evolution of airship technology incorporating the applicable advances in modern aerospace technology. This study was accomplished in four parts as follows.

1.1.1 Historical Overview

An extensive search of literature of the past 75 years as well as present writings has been conducted to establish the state-of-the-art comparisons between 1930 airship technology and that available in 1975. These comparisons were defined in the following: vehicle performance, propulsion, avionics and instruments, control systems, materials and structures, operating procedures, and economics.

1.1.2 Survey of Missions

Many potential civil transportation requirements were investigated and analyzed to define missions for which the airship may be best suited or uniquely applicable. The transcontinental freight mission, initially carrying a 50 ton (45,500 Kg) payload over 2000 n.mi. (3700 Km) was established as the most promising airship mission. Development of a vehicle in this category would have fallout in other missions as well as lead to larger airships.

1.1.3 Vehicle Parametric Design

A literature search uncovered nearly 50 recent airship concepts that were identified as potential advanced vehicle concepts. A survey of their characteristics led to grouping of the concepts into seven categories from which six of the most

representative concepts were selected for evaluation in the preliminary design and parametric analysis:

- o Conventional Non-Rigid Airship
- o Conventional Rigid Airship
- o Deltoid (Dynairship)
- o Guppoid (Megalifter)
- o Helipsoid
- o Heli-Stat

Preliminary design layouts of each of these concepts were made, sizing and geometry trends established, and through the use of the "CASCOMP" computer program (Appendix C), payload and weight/performance trends defined for a range of parametric variables:

Gross Weight	3,000 lb (1365 kg) to 6,000,000 lb. (2,720,000 kg)
Buoyancy Ratios	.35, .75, 1.00
Cruise Speed	50, 100, 200 kts. (25.7, 51.4, 102.9 m/s)
Range	300, 2000, 5000 n.m. (556, 3,704, 9,260 km)

1.1.4 Selection of Vehicle/Mission Candidates

For each candidate mission, maximum specific productivity - (payload) x (speed) : (weight empty) (PV/E) - was determined for the six candidate vehicle concepts. In every mission case analyzed, except for the 5000 n.mi. range Intercontinental mission, the Helipsoid concept appears superior by a wide margin and is therefore selected as the vehicle concept demonstrating the highest potential for a future airship.

On the basis that an airship must be able to compete economically in the transcontinental (medium range) freight transport area, combined with the better potential of the Helipsoid concept to provide the low operating costs necessary to compete, the 2000 n.mi. (3700 km) range transcontinental mission carrying 100,000 lbs (45,500 kg) payload and the Helipsoid vehicle are selected as the most promising vehicle/mission combination for detailed study in Phase II.

1.2 Conclusions and Recommendations

Conclusions from the Boeing Vertol Company studies of potential future airship missions and vehicles indicate that we should not try to solve today's and future transportation problems with 1930 (or even 1950) vintage airship concepts. A partially bouyant lifting body concept such as the Helipsoid selection can provide superior productivity over all other concepts evaluated. In addition, a partially bouyant Helipsoid

concept of the optimum bouyancy ratio has the potential to solve the critical problems facing a future airship development program, such as:

- o Ballast and Ballast Recovery
- o Low-Speed Controllability
- o Susceptability to Wind/Gusting
- o Weather/Icing Constraints
- o Ground Handling/Hangaring
- o Direct/Indirect Operating Costs

Therefore, Phase II of this "Feasibility of Modern Airship" Program should concentrate on a detailed optimization of the Helipsoid Airship for the transcontinental freight mission, develop accurate economic and operational data in comparison with competing modes of transportation, and identify/program critical research and technology.

In addition, further in-depth studies are recommended to explore preliminary design, wind tunnel and model testing, and feasibility of a technology demonstrator program.

2. INTRODUCTION

A renewed interest in the use of lighter than air (LTA) vehicles has gradually grown over the past decade. Claims have been made that the airship would be an "ecological" vehicle, using less fuel than aircraft, causing less air pollution, having inherent high productivity in the larger sizes, and being capable of performing a variety of transportation missions. Hybrids, partial buoyancy airships, also entered as viable candidates. However, no systematic and thorough analyses of the possible capabilities of a modern airship have ever been conducted.

To find out about what an airship really can do in the 1975's era with its severe competition within the field of transportation and to determine the facts in the light of 1975's technology, the National Aeronautics and Space Administration, Ames Research Center (NASA Ames) issued a Request for Proposal and consequently awarded one of the two contracts to the Boeing Vertol Company.

The objectives of the study are as follows: (1) Provide a historical overview of the missions, vehicle configurations, performance, technology, and costs of airships of the past; (2) Identify concepts for airships which are fully or partially bouyant and conduct a parametric study of these concepts to investigate the tradeoffs among aerodynamic performance, propulsion requirements, and structural requirements; and (3) identify missions for which airships are uniquely suited or potentially competitive.

The Phase I program for which results are presented in this report, consisted of four separate tasks. Their interface between each other and integration into the report task is illustrated in Figure 2-1.

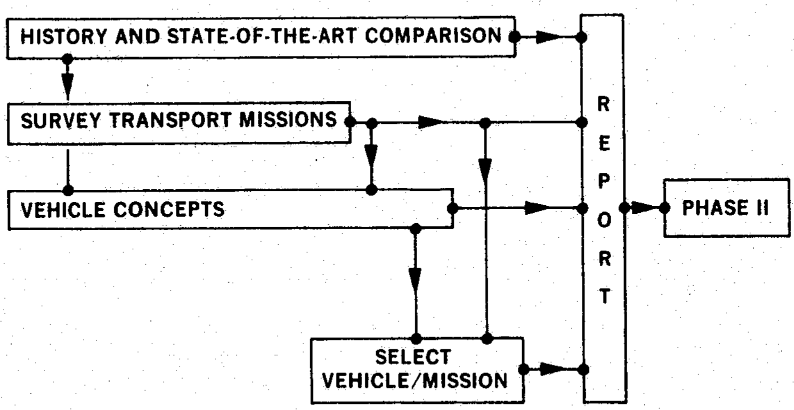


Figure 2–1. Phase I Program

In the following, a brief description of the execution of the different task elements is given.

2.1 History and State-of-the-Art Comparison

An extensive search of old and new literature has been conducted. Pertinent data on past airships were collected to serve as a baseline for developing concepts utilizing 1975's technology.

The state-of-the-art comparison between 1930 and 1975 concentrated on the more meaningful and important areas and systems, namely: vehicle performance, propulsion, avionics and instruments, control systems, materials and structures, operating procedures, and economics. The 1930's and 1975's technology was investigated and is discussed in this report and the technology status defined.

2.2 Survey and Transport Missions

In this task missions within the field of freight, passenger and surveillance have been analyzed. The freight mission category has included very heavy lift missions, natural gas transport, and the freight commodity market. The passenger missions have considered corridor traffic as well as suburban commuter traffic. U.S. Coast Guard and police missions have been considered and evaluated amongst surveillance missions.

Military potential missions within the U.S. Navy and U.S. Air Force, based upon input from the mentioned services, are listed as candidates. No analysis of them have been done inasmuch as military missions were outside the specified study work.

2.3 Vehicle Concepts

A literature search uncovered nearly 50 recent airship concepts that were identified as potential advanced vehicle concepts. A survey of their characteristics led to grouping of the concepts into several categories from which the following six most representative concepts were selected for evaluation in the preliminary design and parametric analysis:

- Conventional Non-Rigid Airship
- Conventional Rigid Airship
- Deltoid (Dynairship)
- Guppoid (Megalifter)
- Helipsoid
- Heli-Stat

Preliminary design layouts of each of these concepts were laid down, sizing and geometry trends established, and through the use of the "CASCOMP" computer program payload and weight/performance trends defined for a range of parametric variables.

For each candidate mission, maximum specific productivity (PV/E) was determined for the six candidate vehicle concepts. Using the specific productivity index as a figure of merit, the most promising vehicle was selected to match the mission selection.

Page

3. HISTORICAL OVERVIEW

The feasibility and capability of a modern airship is dependent upon what missions can be performed in a better way by the airship and what improvements can be implemented by applying 1975's technology. However, before such an analysis can be made in a meaningful way, it is necessary to learn about the past airships, their characteristics, performance, uses and missions. The capability of 1930's technology must also be considered.

A thorough search of literature, documents, reports, etc. has been done to establish the past to serve as a baseline for the analysis of the modern airship.[1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,19,21,38,74,75,76,77,78,79,80]

The past history and a comparison of the 1930's and 1975's technology are presented in the following paragraphs.

3.1 History, Uses and Missions

3.1.1 Brief History

Man's earliest attempt to become airborne was to imitate the birds; nature's way to give air mobility to a creature. However, two major problems stopped him in his attempt. Not until several hundred years later did the understanding of aerodynamics and availability of sufficiently light powerplants make possible flights based upon the dynamic lift principle, also called the heavier-than-air principle.

Meanwhile, the early imitations of the bird's flight was surpassed by man's innovative imagination. When the rising heat from a fire was captured, a manmade object heavier than air became airborne by using static lift. The lighter-than-air vehicle principle was born.

On 21 November 1783, Pilâtre de Rozier and the Marquis d'Arlandes became the first men to make a free-balloon flight. It was made over Paris in a hot-air balloon, manufactured by the Montgolfier Brothers, Jacques Etienne and Joseph, French paper manufacturers. On 1 December in the same year, the first hydrogen-filled balloon with J. A. C. Charles, a French professor in Physics, together with the manufacturer of the balloon, ascended to 2,000 ft (610 m).[38]

To be airborne was one thing. To go places was another. The balloon was at the mercy of the winds. Where the wind blew, there you went.[77] It became apparent that some sort of propulsion strong enough to overcome a reasonable headwind, was required if flying should be useful. Many schemes with sails muscle power, steam engines, battery-driven eletric motors, etc. driving one or more propellers were conceived. It was not until the end of the 19th century when a relatively light engine developing sufficient power materialized, the balloon came under man's power. The airship, the powered and steerable balloon (the dirigible), was born.

Much has been written about airships, especially during the late 1960's and early 1970's. This review will be limited to a brief discussion of the three airship concepts - non-rigid, semi-rigid and rigid. Characteristics and data of a large number of airships were collected from different sources.[1,3,4,5,6,7,9] The lifting performance has been normalized to a common denominator, International Standard Atmosphere, Sea Level (ISA SL). In the search of data, much contradictory information was found. The values that were selected for tabulation are the most probable ones.

The development history of airships is illustrated in Figure 3-1. France, where the first practical balloons were developed, continued to lead in the early development of controlled air mobility. In 1852, Giffard flew his non-rigid airship under some acceptable controlled conditions and at a speed of 6 mi/hr (2.68 m/s) over Paris. The early 1900's saw the real breakthrough when Santos-Dumont flew a closed-circuit course in Paris circling the Eiffel Tower. Continuing development produced non-rigid type airships of models such as Astra and Zodiac which saw service in WW I. Several airships were exported to Belgium, England, Russia and U.S.A.; England also produced several non-rigid airships under license from France in addition to domestic designs during WW I.

Development and manufacture of non-rigid airships started early in the U.S.A. with Baldwin. Starting in the beginning of WW I several non-rigid airships were designed by the Bureau of Aeronautics, U.S. Navy and by U.S. Army Engineering Division. They were built by various manufacturers, such as Aircraft Development Corporation of Detroit (except envelopes), Airship, Inc., Hammondsport, N. Y., Connecticut Aircraft Company, B. F. Goodrich Co., Goodyear Tire & Rubber Company, Naval Aircraft Factory, Philadelphia, Pa. (except envelopes).[1]

Parceval in Germany built his first non-rigid airship around 1910. Several were produced and used in WW I in a very

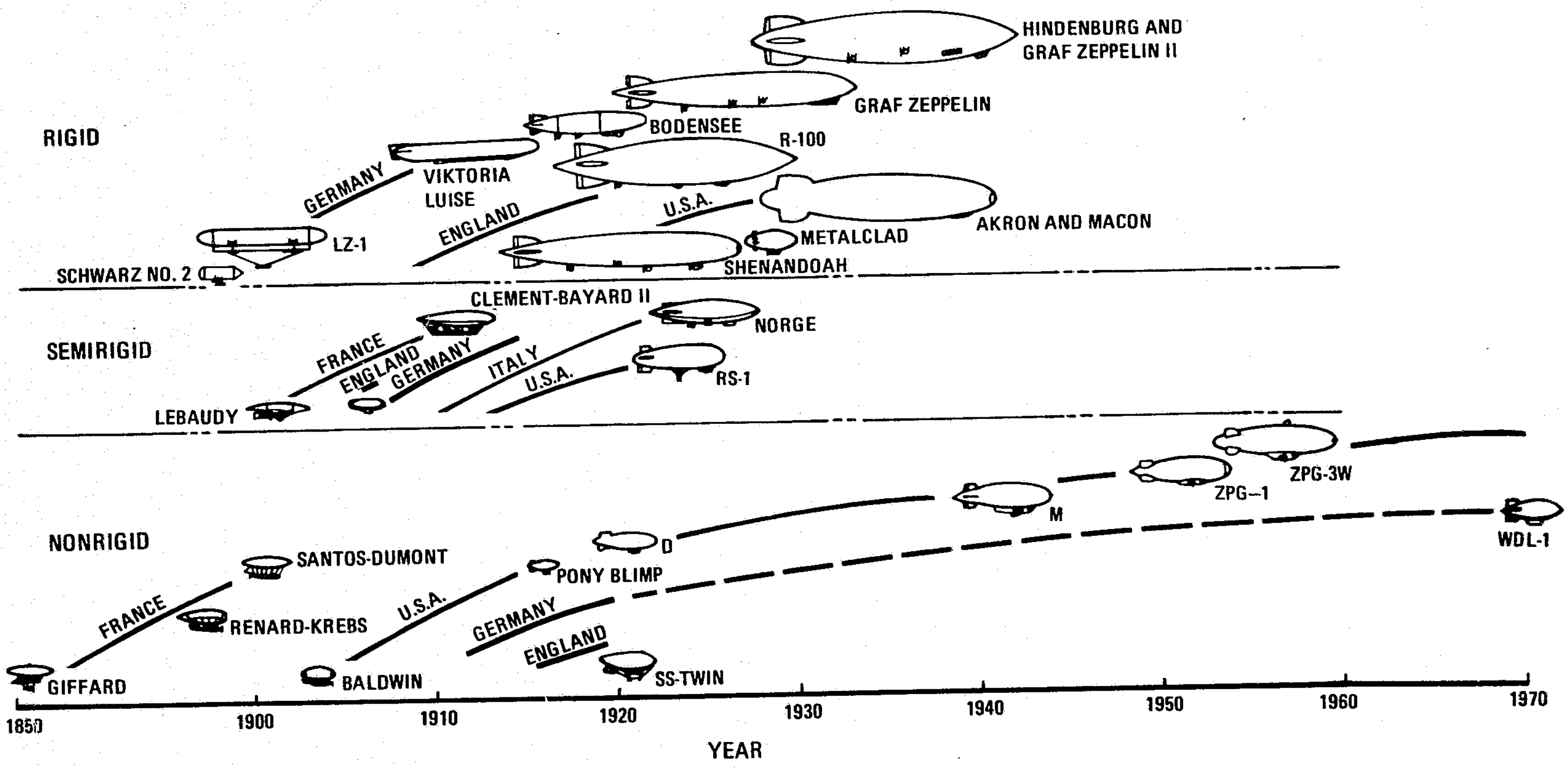


Figure 3–1. History of Airship Development

limited degree. Parceval airships were also licensed and produced in Austria-Hungary and Japan. A Japanese design, Yamada, a non-rigid airship was produced in the 1910-12 time period. The airship era in Italy started in 1905 with "Italia I", a non-rigid. It had a unique feature in that the bottom of the envelope was made of rubber in lieu of ballonets.

Very little documented evidence on Russian activity has been found, but at least some data on a 1946 non-rigid airship has been uncovered.

Characteristics of representative non-rigid airships are tabulated in Table 3-I. Contours of some of them are reproduced in Figure 3-2 to the same scale.

Meanwhile the semi-rigid airship emerged because it was thought that when the size of an airship grew, the semi-rigid concept should be lighter than a non-rigid inasmuch as the inflation pressure of the envelope could be less. The non-rigid must rigidize the envelope by pressure, calling for a heavier fabric, while the semi-rigid has the help of a structure. This theory has never been proven. In fact it turned out that the keel structure became rather heavy. See Figure 3-5.

Italy became the main producer of semi-rigids. Some of them became famous, such as "Norge" and "Italia" with their Arctic flights. A few were produced in France and Germany, and one in the U.S.A. by the Goodyear Tire & Rubber Co., the RS-1 for the U.S. Army in 1925. General Umberto Nobile, of the Stabilimento di Construzioni Aeronautica, Rome, who was behind most of the successful Italian semi-rigid designs, served as a consultant.[1] A few data on a Russian semi-rigid airship have also been found. Table 3-II gives the characteristics of selected semi-rigid airships and Figure 3-3 shows some contours to the same scale as the non-rigids and rigids.

In 1897, Austrian Schwarz's aluminum covered rigid airship made its first and only flight. The rigid hull contained several individual gas cells, but it leaked to such a degree that after 4 miles (6.436 km) it plunged to the ground and was a loss. This was, however, the initiation of the German era in rigid airship design. Count Ferdinand von Zeppelin's devoted work produced a total of 119 airships between 1900 and 1938. Another 19 rigid airships were designed and produced by Schütte-Lanz between 1911 and 1917. Many of Schütte-Lanz features were superior to the Zeppelin design. Out of the combined resources and patents grew the L-30 class "Super-Zeppelins".[12]

Table 3–I. Characteristics of Representative Non-Rigid Airships (Sheet 1 of 2)

COUNTRY	YEAR, FIRST FLIGHT OF TYPE	TYPE AND NAME	DIMENSIONAL DATA GAS VOLUME x 10^3 ft^3 *m^3*	 LENGTH ft *m*	 DIAMETER MAXIMUM ft *m*	 FINENESS RATIO	WEIGHT AND LIFT DATA STATIC GROSS LIFT x 10^3 lb *kg*	 OPERATIONAL WEIGHT EMPTY x 10^3 lb	 USEFUL LIFT X 10^3 lb *kg*	 USEFUL LIFT: GROSS LIFT RATIO %	ENGINE DATA QUANTITY	 TOTAL POWER hp	PERFORMANCE DATA SPEED, MAXIMUM kt *m/s*	 PRESSURE ALTITUDE x 10^3 ft *m*	ILLUSTRATION FIGURE 3–2
USA	1915	Navy A	110.00 *3.12*	175.0 *53.3*	35.0 *10.7*	5.0	7.44 *3.37*	5.83 *2.64*	1.61 *.73*	21.6	1	140	30.4 *15.64*	6.0 *1.83*	
	1917	Pony Blimp A	35.35 *1.00*	95.5 *29.1*	28.0 *8.5*	3.4	2.39 *1.08*	1.46 *.66*	.93 *.42*	38.9	1	40	34.8 *17.90*	6.0 *1.83*	
	1917	Navy B	84.0 *2.38*	163.0 *49.7*	31.5 *9.6*	5.2	5.68 *2.58*	3.60 *1.63*	2.08 *.95*	36.6	1	100	40.8 *20.99*	8.5 *2.59*	
	1918	Navy C	181.00 *5.13*	196.0 *59.7*	42.0 *12.8*	4.7	12.24 *5.55*	7.60 *3.45*	4.64 *2.10*	37.9	2	300	52.1 *26.80*	8.6 *2.62*	
	1918	Navy E	95.00 *2.69*	162.0 *49.4*	33.5 *10.2*	4.8	6.42 *2.91*	4.54 *2.06*	1.88 *.85*	29.3	1	150	48.7 *25.05*	8.0 *2.44*	
	1918	Navy F	95.00 *2.69*	162.0 *49.4*	33.5 *10.2*	4.8	6.42 *2.91*	4.29 *1.95*	2.13 *.96*	33.2	1	125	45.2 *23.25*	8.0 *2.44*	
	1919	Navy D	190.00 *5.38*	198.0 *60.4*	42.0 *12.8*	4.7	12.24 *5.55*	7.90 *3.58*	4.34 *1.97*	35.5	2	250	50.4 *25.93*	8.8 *2.68*	A
	1919	Army A-4	95.00 *2.69*	162.0 *49.4*	33.5 *10.2*	4.8	6.42 *2.91*	4.20 *1.91*	2.22 *1.00*	34.7	1	90	40.0 *20.58*	8.0 *2.44*	B
	1920	Army OA-1	35.35 *1.00*	95.5 *29.1*	28.0 *8.5*	3.4	2.39 *1.08*	1.50 *.68*	.89 *.40*	37.4	1	50	39.1 *20.11*	6.0 *1.83*	
	1921	Army US-MB	49.68 *1.41*	109.0 *33.2*	29.8 *9.1*	3.7	3.35 *1.52*	2.16 *.98*	1.20 *.54*	35.6	2	120	47.8 *24.59*	6.0 *1.83*	
	1921	Army MA	180.00 *5.10*	169.0 *51.5*	48.0 *14.6*	3.5	12.17 *5.52*	7.65 *3.47*	4.52 *2.05*	37.1	2	260	56.5 *29.07*	10.5 *3.20*	
	1922	Army OB-1	43.00 *1.22*	94.8 *28.9*	30.8 *9.4*	3.1	2.91 *1.32*	1.76 *.80*	1.15 *.52*	39.4	1	50	39.1 *20.11*	6.0 *1.83*	C
	1922	Navy-1	173.00 *4.90*	170.5 *52.0*	45.0 *13.7*	3.8	11.70 *5.31*	7.00 *3.18*	4.70 *2.13*	40.2	2	260		9.3 *2.83*	
	1922	Army TC-1 Class	200.00 *5.66*	196.0 *59.7*	44.5 *13.6*	4.4	11.58 *5.25*	7.47 *3.39*	4.11 *1.86*	35.5	2	300	45.2 *23.25*	8.0 *2.44*	
	1923	Army TA-1 Class	130.16 *3.69*	162.0 *49.4*	39.3 *12.0*	4.1	7.54 *3.42*	5.67 *2.57*	1.87 *.85*	25.0	2	160	39.1 *20.11*		
	1924	Army TC-6	200.60 *5.68*	196.0 *59.7*	44.5 *13.6*	4.4	11.58 *5.25*	7.51 *3.41*	4.07 *1.84*	35.2	2	380	50.4 *25.93*		D
	1926	Army TE-1	80.20 *2.27*	136.0 *41.5*	34.0 *10.4*	4.0	4.63 *2.10*	3.30 *1.50*	1.33 *.60*	28.8	2	80	39.1 *20.11*		
	1926	Army TF-1	52.29 *1.48*	106.0 *32.3*	30.9 *9.4*	3.4	2.87 *1.30*	1.94 *.88*	.93 *.42*	32.5	1	40	34.8 *17.90*		
	1931	K-1	319.00 *9.03*	218.0 *66.4*	54.0 *16.5*	4.0	20.56 *9.33*	12.88 *5.84*	7.68 *4.09*	37.4	2	600	55 *28.29*	13.0 *3.96*	E
	1945	K-15	456.00 *12.91*	253.0 *77.1*	60.0 *18.3*	4.2	27.40 *12.43*	20.30 *9.21*	7.10 *3.22*	25.9	2	1,200	67.5 *34.72*	10.0 *3.05*	
	1944	M-4	725.00 *20.53*	310.0 *94.5*	68.0 *20.7*	4.6	44.95 *20.39*	31.50 *14.29*	13.45 *6.10*	29.9	2	1,100	69.0 *35.50*	11.4 *3.47*	
	1951	ZPG-1	875.00 *24.78*	324.0 *98.8*	74.0 *22.6*	4.4	52.62 *23.87*	40.15 *18.21*	12.47 *5.66*	23.7	2	1,600	74.0 *38.07*	10.8 *3.29*	

Table 3–I. Characteristics of Representative Non-Rigid Airships (Sheet 2 of 2)

COUNTRY	YEAR, FIRST FLIGHT OF TYPE	TYPE AND NAME	DIMENSIONAL DATA: GAS VOLUME x 10^3 ft *m^3*	DIMENSIONAL DATA: LENGTH ft *m*	DIMENSIONAL DATA: DIAMETER MAXIMUM ft *m*	DIMENSIONAL DATA: FINENESS RATIO	WEIGHT AND LIFT DATA: STATIC GROSS LIFT x 10^3 lb *kg*	WEIGHT AND LIFT DATA: OPERATIONAL WEIGHT EMPTY x 10^3 lb *kg*	WEIGHT AND LIFT DATA: USEFUL LIFT X 10^3 lb *kg*	WEIGHT AND LIFT DATA: USEFUL LIFT: GROSS LIFT RATIO %	ENGINE DATA: QUANTITY	ENGINE DATA: TOTAL POWER hp	PERFORMANCE DATA: SPEED, MAXIMUM kt *m/s*	PERFORMANCE DATA: PRESSURE ALTITUDE x 10^3 ft *m*	ILLUSTRATION FIGURE 3–2
USA	1953	ZPG-2	975.00 *27.61*	343.0 *104.5*	75.0 *22.9*	4.6	61.91 *28.08*	46.30 *21.00*	15.61 *7.08*	25.2	2	1,600	73.0 *37.55*	9.5 *2.90*	
	1955	ZPG-2W	975.00 *27.61*	343.0 *104.5*	75.0 *22.9*	4.6	61.91 *28.08*	47.78 *21.67*	14.13 *6.41*	22.8	2	1,800	70.5 *36.27*	9.5 *2.90*	F
	1959	ZPG-3W	1,490.00 *42.20*	403.0 *122.8*	85.0 *25.9*	4.7	94.62 *42.92*	67.57 *30.65*	27.05 *12.27*	28.6	2	2,550	82.0 *42.18*	9.6 *2.93*	
	1963	GZ-19A Columbia II	147.3 *4.17*	157.0 *47.9*	42.0 *12.8*	3.7	8.78 *3.98*	6.40 *2.90*	2.38 *1.08*	27.1	2	350	48.5 *24.95*	10.0 *3.05*	
FRANCE	1915	Astra	495.00 *14.02*	295.0 *89.9*	54.0 *16.5*	5.5	31.88 *14.46*	17.25 *7.82*	14.63 *6.64*	45.9	2	440	34.8 *9.67*		
	1915	Zodiac (D'Arl & Champ)	501.00 *14.19*	303.0 *92.4*	52.8 *16.1*	5.7	32.26	18.36	13.90	43.1	2	440	37.4 *10.39*		
	1916	Lorraine & Tunisie	370.60 *10.50*	306.0 *93.3*	46.2 *14.1*	6.6	23.87	13.89	9.98	41.8	2	440	37.6 *10.44*		
	1917	Captain Caussin	321.90 *9.12*	273.0 *83.2*	46.2 *14.1*	5.9	20.73	9.63	11.10	53.5	2	480	46.9 *13.03*		
	1918	AT-19	339.00 *9.60*	262.4 *80.0*	54.1 *16.5*	4.9	21.83 *9.90*	12.85 *5.83*	8.98 *4.07*	41.1	2	500	43.4 *12.06*		
	1918	Vedette-Zodiac (VZ 1-15)	97.00 *2.75*	156.0 *47.5*	35.6 *10.9*	4.4	6.25				2	160	41.7 *11.58*		
GERMANY	1912	PL-17	353.14 *10.00*	278.7 *84.9*	52.5 *16.0*	5.3	22.74 *10.31*	17.99 *8.16*	4.75 *2.15*	20.9	2	340	35.0 *9.72*	6.6 *2.0*	
	1913	PL-16	353.14 *10.00*	308.4 *94.0*	50.8 *15.5*	6.1	22.74 *10.31*	16.64 *7.55*	6.10 *2.76*	26.8	2	360	36.7 *10.19*	6.6 *2.0*	
	1914	PL-23	353.14 *10.0*	301.8 *92.0*	49.2 *15.0*	6.1	22.74 *10.31*	16.87 *7.65*	5.87 *2.66*	25.8	2	400	37.7 *10.47*	8.2 *2.5*	
	1921	PL-3	317.90 *9.00*	283.1 *86.3*	48.3 *14.7*	5.9	20.47 *9.29*	11.57 *5.25*	8.90 *4.04*	43.5	2	520	58.2 *16.17*	13.1 *4.0*	
	1972	WDL-1	211.86 *6.00*	180.5 *55.0*	47.6 *14.5*	3.8	13.89 *6.30*	10.60 *4.8*	3.29 *1.50*	23.8	2	500	60.8 *31.29*		H
ENGLAND	1916	SS	65.00 *1.84*	144.0 *43.9*	28.0 *8.5*	5.1	4.18 *1.90*	2.95 *1.34*	1.23 *.56*	29.4	1	80	39.1 *10.86*		
	1917	SS Zero	70.00 *1.98*	143.0 *43.6*	32.0 *9.8*	4.5	4.51 *2.05*	4.19 *1.90*	.32 *.15*	7.1	1	75	42.1 *11.69*		
	1918	SS Twin	100.00 *2.83*	165.0 *50.3*			6.44 *2.92*	4.75 *2.15*	1.69 *.77*	26.2	2	150	50.0 *13.89*	10.0 *3.05*	G
		C-Star	210.00 *5.95*	218.0 *66.4*			13.52 *6.13*	10.43 *4.73*	3.09 *1.40*	22.8	1	110	50.0 *13.89*		
USSR	1946	Patriot		131.2 *48.0*							2	290	54.0 *27.78*		

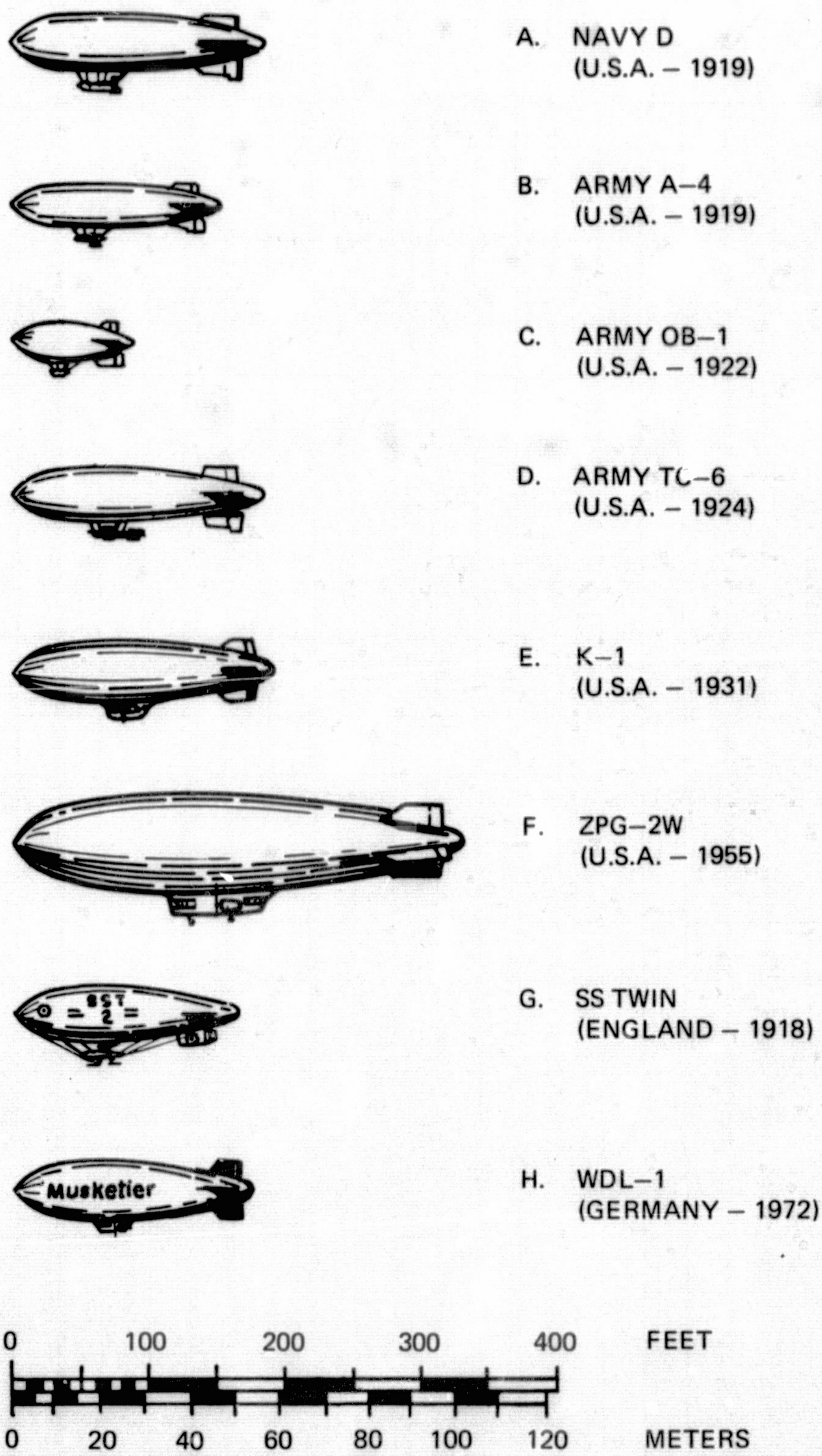


Figure 3–2. Contours of Some Non-Rigid Airships

Table 3–II. Characteristics of Representative Semi-Rigid Airships (Sheet 1 of 2)

COUNTRY	YEAR	TYPE	DIMENSIONAL DATA: GAS VOLUME $\times 10^3$ ft^3 / *m^3*	DIMENSIONAL DATA: LENGTH ft / *m*	DIMENSIONAL DATA: DIAM, MAX ft / *m*	DIMENSIONAL DATA: FINENESS RATIO	WEIGHT AND LIFT DATA: STATIC GROSS LIFT $\times 10^3$ lb / *kg*	WEIGHT AND LIFT DATA: OPERATIONAL WEIGHT EMPTY $\times 10^3$ lb / *kg*	WEIGHT AND LIFT DATA: USEFUL LIFT $\times 10^3$ lb / *kg*	USEFUL LIFT: GROSS LIFT %	ENGINE DATA: INSTALLED POWER	PERFORMANCE DATA: SPEED, MAX kt / *m/s*	ILLUSTRATION FIGURE 3–3
U.S.A.	1925	RS-1	745.00 *21.10*	282.0 *85.0*	70.0 *21.3*	4.0	54.00 *24.49*	30.37 *13.78*	23.63 *10.72*	43.8	1,200	60.8 *31.30*	A
ITALY	1909	P	173.02 *4.90*	203.4 *62.0*	41.3 *12.6*	4.9	12.44 *5.64*	8.38 *3.80*	4.06 *1.84*	32.6	140	35.1 *18.06*	
		PV	183.61 *5.20*	203.4 *62.0*	42.3 *12.9*	4.8	13.19 *5.98*	8.82 *4.00*	4.37 *1.98*	33.1	380	48.5 *24.97*	
		M	441.38 *12.50*	271.3 *82.7*	55.4 *16.9*	4.9	31.71 *14.38*	18.08 *8.20*	13.63 *6.18*	43.0	390	37.8 *19.44*	
		V-2	554.37 *15.70*	285.8 *87.1*	67.9 *20.7*	4.2	39.82 *18.06*	25.14 *11.40*	14.69 *6.66*	36.9	540	42.1 *21.67*	
		E	91.81 *2.60*	158.8 *48.4*	33.1 *10.1*	4.8	6.59 *2.99*	3.97 *1.80*	2.62 *1.19*	39.8	100	36.7 *18.89*	
		O	127.12 *3.60*	177.8 *54.2*	35.4 *10.8*	5.0	9.13 *4.14*	5.84 *2.65*	3.29 *1.49*	36.0	240	49.1 *25.28*	
	1922	OS	175.49 *4.97*	222.1 *67.7*	44.6 *13.6*	5.0	12.57 *5.70*	7.06 *3.20*	5.51 *2.50*	43.8	480	45.9 *23.61*	
		A	635.58 *18.00*	321.5 *98.0*	60.7 *18.5*	5.3	45.64 *20.70*	22.05 *10.00*	23.59 ? *10.70 ?*	51.7 ?	950	43.2 *22.22*	
		SCA-1	52.97 *1.50*	129.6 *39.5*	27.9 *8.5*	4.6	3.81 *1.73*	2.38 *1.08*	1.43 *.65*	37.5	80	44.5 *22.92*	
		PM	186.08 *5.27*	220.2 *67.1*	44.6 *13.6*	4.9	13.40 *6.08*	8.66 *3.93*	4.74 *2.15*	35.4	380	50.9 *26.22*	
	1909	U	141.24 *4.00*	180.5 *55.0*	34.8 *10.6*	5.2	10.14 *4.60*	6.62 *3.00*	3.53 *1.60*	34.8	240	38.7 *19.92*	
	1920	T-34 (Roma)	1,239.38 *35.10*	410.1 *125.0*	74.5 *22.7*	5.5	89.08 *40.40*	47.19 *21.40*	41.90 *19.00*	47.0	2,100	59.3 *30.50*	D
	1926	N-1 (Norge)	653.24 *18.50*	347.8 *106.0*	64.0 *19.5*	5.4	46.92 *21.28*	28.67 *13.00*	18.25 *8.28*	38.9	750	61.0 *31.39*	E
	1926	N-3	264.83 *7.50*	265.8 *81.0*	60.0 *18.3*	4.4	19.07 *8.65*	12.45 *5.65*	6.62 *3.00*	34.7	480	64.8 *33.33*	
	1909	F1 (Leonardo da Vinci)	130.65 *3.70*	131.2 *40.0*	45.9 *14.0*	2.9	9.41 *4.27*	6.17 *2.80*	3.24 *1.47*	34.4	40	27.0 *13.89*	
	1912	F2 (Citta di Milano)	459.03 *13.00*	236.2 *72.0*	59.1 *18.0*	4.0	33.05 *15.00*	18.52 *8.40*	14.55 *6.60*	44.0	170	34.0 *17.50*	
		F3 (Citta di Jesi)	529.65 *15.00*	295.3 *90.0*	59.1 *18.0*	5.0	38.13 *17.30*	23.15 *10.56*	14.99 *6.80*	39.3	400	40.5 *20.83*	
		F4	529.65 *15.00*	295.3 *90.0*	59.1 *18.0*	5.0	38.13 *17.30*	20.51 *9.30*	17.64 *8.00*	46.3	320	39.4 *20.28*	
		F5	670.89 *19.00*	295.3 *90.0*	65.6 *20.0*	4.5	48.30 *21.91*	21.39 ? *9.70 ?*	26.92 ? *12.21 ?*	55.7 ?	480	37.8 *19.44*	
	1918	F6	670.89 *19.00*	295.3 *90.0*	65.6 *20.0*	4.5	48.30 *21.91*	22.71 ? *10.30 ?*	25.60 ? *11.61 ?*	53.0 ?	760	40.5 *20.83*	

Table 3–II. Characteristics of Representative Semi-Rigid Airships (Sheet 2 of 2)

COUNTRY	YEAR	TYPE	DIMENSIONAL DATA: GAS VOLUME x 10³ ft³ *m³*	DIMENSIONAL DATA: LENGTH ft *m*	DIMENSIONAL DATA: DIAM, MAX ft *m*	DIMENSIONAL DATA: FINENESS RATIO	WEIGHT AND LIFT DATA: STATIC GROSS LIFT x 10³ lb. *kg*	WEIGHT AND LIFT DATA: OPERATIONAL WEIGHT EMPTY x 10³ lb *kg*	WEIGHT AND LIFT DATA: USEFUL LIFT x 10³ lb *kg*	USEFUL LIFT & GROSS LIFT %	ENGINE DATA: INSTALLED POWER hp	PERFORMANCE DATA: SPEED, MAX kt *m/s*	ILLUSTRATION FIGURE 3–3
GERMANY	1907	M-Exp.	63.56 *1.80*	131.2 *40.0*	26.9 *8.2*	4.9	4.56 *2.07*	3.53 *1.60*	1.04 *.47*	22.8	24	17.5 *9.03*	
		M-I	176.55 *5.00*	214.9 *65.5*	36.4 *11.1*	5.9	12.68 *5.75*	9.68 *4.39*	3.00 *1.36*	23.7	150	24.8 *12.28*	
		M-II	275.42 *7.80*	267.4 *81.5*	42.7 *13.0*	6.3	19.80 *8.98*	14.88 *6.75*	4.92 *2.23*	24.8	300	27.0 *13.89*	
	1909	M-III	388.41 *11.00*	315.0 *96.6*	45.0 *14.0*	6.9	27.92 *12.66*	21.96 *9.96*	5.95 *2.70*	21.3	600	32.9 *16.94*	
	1914	M-IV	476.69 *13.50*	323.1 *98.5*	50.2 *15.3*	6.4	34.22 *15.52*	27.17 *12.32*	7.06 *3.20*	20.6	480	44.5 *22.92*	C
FRANCE	1910	CB-II	247.00 *7.00*	251.0 *76.5*	43.3 *13.2*	5.8	17.78 *8.07*				200		B
	1910	La Liberte	170.00 *4.81*	220.0 *67.1*	35.5 *10.8*	6.2	12.24 *5.55*				135	26.9 *13.85*	
	1911	Capitaine Marschall	263.00 *7.45*	279.0 *85.0*	42.0 *12.8*	6.6	18.94 *8.59*				160	24.3 *12.51*	
	1912	Selle De Beauchamp	280.00 *7.93*	292.0 *89.0*	48.0 *14.6*	6.1	20.16 *9.14*				160	24.3 *12.51*	
U.S.S.R.	1910	JASTREV	52.97 *1.5*								75	11.3 *5.81*	

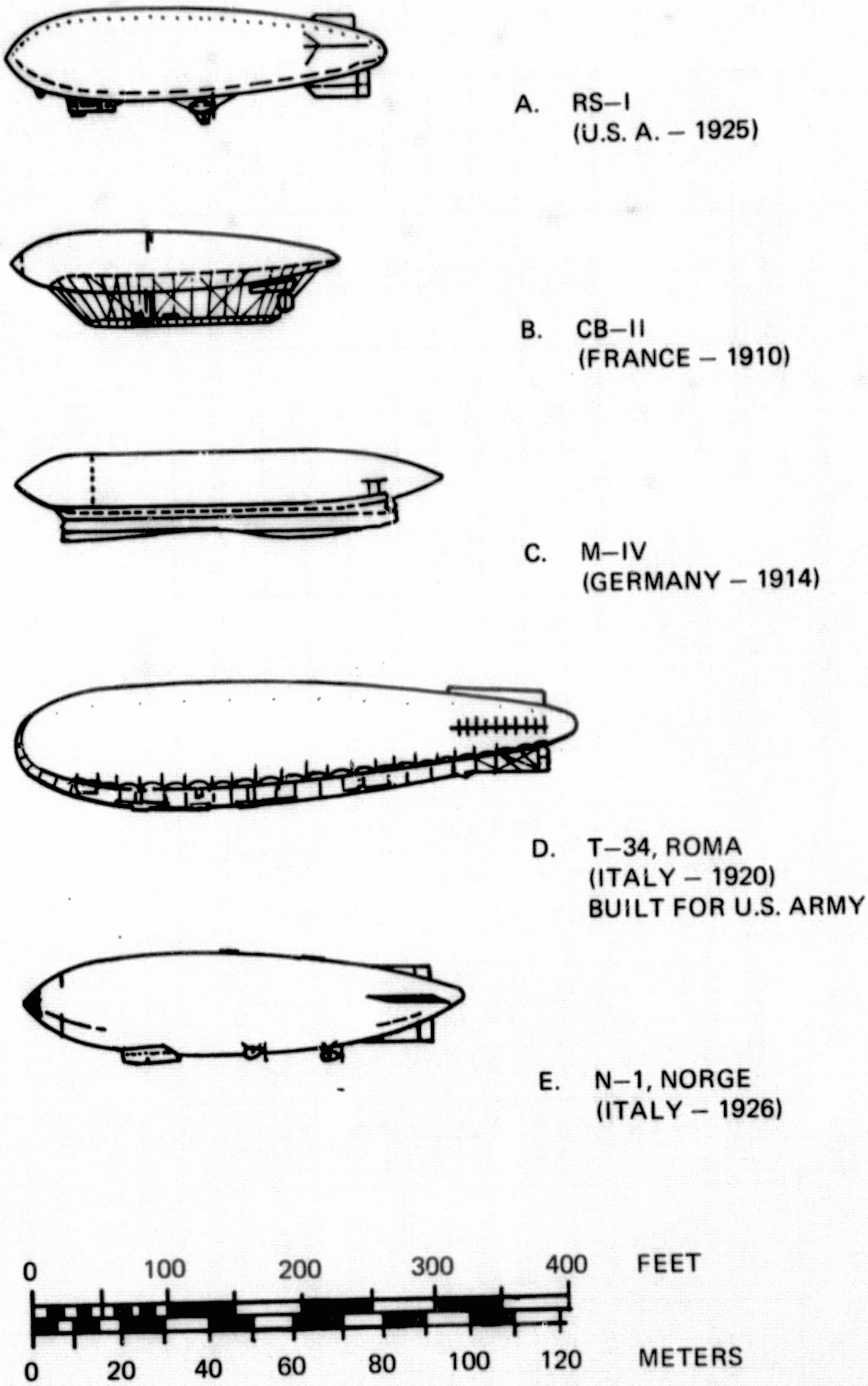


Figure 3–3. Contours of Some Semi-Rigid Airships

The U.S.A. has produced four rigid airships, all of them of original design. They all saw extensive service except for the all-metal ZMC-2 which was an experimental airship. It is noteworthy to mention that both the Akron and Macon had facilities to hangar, launch and retrieve fighter type aircraft in the air. Three (ZMC-2 excluded; it was dismantled) were destroyed in bad weather.

Some airships were built in England. Most of the designs were based upon German Zeppelins shot down over England during WW I. None of them, including the original design, were really successful and did not see any extensive service. It should be noted, however, that R-34, which design was based upon the shot down L-33, flew a round-trip over the Atlantic in July 1919. The only French rigid, Zodiac XII (Spiess) met an early catastrophe on its first flight.

All of the 157 rigid airships which flew more than a few miles and which have been built in the world since year 1900 are listed in Table 3-III with their characteristics. Contours to uniform scale of some of them are shown in Figure 3-4. Figure 3-5 is an interesting comparison of weight breakdown of typical past non-rigid, semi-rigid, and rigid airships. It shows how the non-rigids low hull weight is offset by the complicated suspension system for the loads (control car, power cars, and disposable loads). It can also be seen that the semi-rigid design does not offer any noticeable weight advantage over the non-rigid. The rigid gives more payload than the non-rigid and the semi-rigid but it should be noted that the great difference in size and year of design of the airships compared makes a relevant conclusion impossible.

More than 900 airships of different types and concepts have been produced. Development work, especially in the field of material, laid the groundwork for future airplane development. Dural, developed in Germany for von Zeppelin's use, and Alclad, developed in the U.S.A. for the ZMC-2 metalclad airship, are examples of the debt airplane designers owe to the airship.

3.1.2 Uses and Missions

3.1.2.1 Civil Uses

The earliest use of an airship for commercial traffic seems to have been in France, starting in the summer of 1909. The 'Compagnie Generale Transaerienne' was then formed and during three summers flew 2,590 passengers, most probably on pleasure and sightseeing tours. The non-rigid Astra type airship Transaerienne I was used.[5] Some statistics from this operation are given in Table 3-IV.

Table 3–III. Characteristics of Representative Rigid Airships (Sheet 1 of 3)

COUNTRY	YEAR, FIRST FLIGHT OF FIRST TYPE	TYPE AND NAME	QUANTITY BUILT	DIMENSIONAL DATA				WEIGHT AND LIFT DATA				ENGINE DATA			PERFORMANCE DATA		ILLUSTR FIG. 3–4
				GAS VOLUME $\times 10^3$ FT^3 m^3	LENGTH ft m	DIAMETER MAXIMUM ft m	FINENESS RATIO	STATIC GROSS LIFT $\times 10^3$ lb kg	OPERATIONAL WEIGHT EMPTY $\times 10^3$ lb. kg	USEFUL LIFT $\times 10^3$ lb kg	USEFUL LIFT: GROSS LIFT %	QUANTITY	TOTAL POWER hp	WEIGHT POWER RATIO lb/hp kg/hp	SPEED MAXIMUM kt m/s	PRESSURE ALTITUDE $\times 10^3$ ft m	
USA	1923	ZR-1 Shenandoah	1	2,115 59.9	680.0 207.3	78.7 24.0	8.6	120.40 54.61	82.83 37.57	44.17 20.04	36.7	6	1,800	3.14 1.43	52.4 26.94		A
	1929	ZMC-2 Metalclad	1	202.2 5.7	149.4 45.5	52.7 16.1	2.8	12.24 5.55	8.90 4.04	3.34 1.52	27.3	2	440	2.31 1.05	56.5 29.05		B
	1931 and 1933	ZRS-4 and 5 Akron & Macon	2	6,500 184.1	785.0 239.3	132.9 40.5	5.9	382.00 173.28	250.76 113.74	152.24 69.06	39.9	8	4,480	4.5 2.04	75.6 38.89		C
GERMANY	1900	LZ1	1	399.0 11.3	420.0 128.0	38.4 11.7	10.9	27.4 12.42	24.45 11.09	2.93 1.33	10.7	2	30	56.7 25.7	15.1 7.78	3.117 .950	D
	1905	LZ3 ZI	2	399.0 11.3	420.0 128.0	38.4 11.7	10.9	27.38 12.42	21.55 9.77	5.85 2.65	21.4	2	170	8.82 4.00	23.8 12.20	3.773 1.150	
	1906	LZ5 ZII	2	529.7 15.0	446.2 136.0	42.7 13.0	10.5	36.58 16.59	26.97 12.23	9.61 4.36	26.3	2	210	8.82 4.00	25.9 13.33	4.101 1.250	
	1909	LZ6	1	565.0 16.0	472.5 144.0	42.7 13.0	11.1	38.87 17.63	30.09 13.65	8.78 3.98	22.6	2	230	8.05 3.65	25.9 13.33	4.265 1.300	
	1910	LZ8 Ersatz Deutchland	2	681.5 19.3	485.6 148.0	45.9 14.9	10.6	46.82 21.23	32.60 14.78	14.22 6.45	30.4	3	360	8.27 3.75	32.4 16.67		
	1911	LZ10 Schwaben	3	628.5 17.8	459.3 140.0	45.9 14.0	10.0	44.32 20.10	29.68 13.46	14.64 6.64	33.0	3	450	6.84 3.10	40.5 20.83		E
	1912	LZ13 Hansa	2	660.3 18.7	485.6 148.0	45.9 14.0	10.6	45.36 20.57	31.78 14.41	13.58 6.16	29.9	3	510	6.17 2.80	43.2 22.22		
	1912	LZ14 L1	1	793.4 22.5	518.4 158.0	48.9 14.9	10.6	54.14 24.55	34.49 15.64	19.65 8.91	36.3	3	510	6.17 2.80	41.6 21.39	10.499 3.200	
	1912	LZ17 Sachsen	5	690.3 19.6	459.3 140.0	48.9 14.9	9.4	47.65 21.61	30.51 13.84	17.14 7.77	36.0	3	540	5.64 2.56	42.1 21.67		
	1913	LZ18 L2	1	953.4 27.0	518.4 158.0	54.5 16.6	9.5	65.63 29.76	42.43 19.24	23.20 10.52	35.3	4	720	5.64 2.56	40.5 20.83	9.515 2.900	
	1913	LZ21 ZVI	1	736.9 20.9	485.6 148.0	48.9 14.9	9.9	50.79 23.03	32.40 14.69	18.39 8.34	36.2	3	540	5.64 2.56	40.0 20.56	9.187 2.800	
	1914	LZ23 ZVIII	2	781.8 22.1	511.8 156.0	48.9 14.9	10.5	53.93 24.46	35.33 16.02	18.60 8.44	34.5	3	540	5.64 2.56	38.9 20.00	9.187 2.800	
	1914	LZ25 ZIX	12	793.4 22.5	518.4 158.0	48.9 14.9	10.6	54.55 24.74	35.32 16.02	19.23 8.72	35.3	3	630	4.34 1.97	45.9 23.61	9.351 2.850	
	1914	LZ26 ZXII	1	882.8 25.0	528.9 161.2	52.5 16.0	10.1	60.83 27.58	35.33 16.02	25.50 11.56	41.9	3	630	4.34 1.97	43.7 22.50	11.812 3.600	
	1915	LZ36 L9	2	879.2 24.9	529.6 161.4	52.5 16.0	10.1	60.62 27.49	37.42 16.97	23.20 10.52	38.3	3	630	4.34 1.97	45.9 23.61	10.171 3.100	
	1915	LZ40 L10	22	1,126.4 31.9	536.4 163.5	61.4 18.7	8.7	75.55 35.17	41.69 19.81	33.86 15.36	44.8	4	960	3.35 1.52	52.9 27.22	12.796 3.900	
	1915	LZ59 L20	12	1,264.1 35.8	585.7 178.5	61.4 18.7	9.5	86.95 39.43	49.54 22.46	37.41 16.97	43.0	4	960	3.35 1.52	51.3 26.39	13.780 4.200	

ORIGINAL PAGE IS OF POOR

Table 3–III. Characteristics of Representative Rigid Airships (Sheet 2 of 3)

COUNTRY	YEAR, FIRST FLIGHT OF FIRST TYPE	TYPE AND NAME	QUANTITY BUILT	DIMENSIONAL DATA GAS VOLUME x 10³ ft³ / *m³*	LENGTH ft / *m*	DIAMETER MAXIMUM ft / *m*	FINENESS RATIO	WEIGHT AND LIFT DATA STATIC GROSS LIFT x 10³ lb. / *kg*	OPERATIONAL WEIGHT EMPTY x 10³ lb. / *kg*	USEFUL LIFT x10³ lb. / *kg*	USEFUL LIFT: GROSS LIFT %	ENGINE DATA QUANTITY	TOTAL POWER hp	WEIGHT POWER RATIO lb/hp / *kg/hp*	PERFORMANCE DATA SPEED, MAXIMUM kt / *m/s*	PRESSURE ALTITUDE X10³ ft / *m*	ILLUSTR FIG. 3–4
GERMANY (CONT.)	1916	LZ62 L30	17	1,949.1 *55.2*	649.6 *198.0*	78.4 *23.9*	8.3	134.19 *60.86*	66.26 *30.05*	67.93 *30.81*	50.6	6	1,440	3.35 *1.52*	55.6 *28.61*	17.717 *5.400*	
	1917	LZ91 L42	2	1,959.7 *55.5*	644.7 *196.5*	78.4 *23.9*	8.2	135.02 *61.24*	58.94 *26.74*	76.08 *34.50*	56.3	5	1,200	3.35 *1.52*	55.1 *28.33*	20.998 *6.400*	
	1917	LZ94 L46	2	1,956.2 *55.4*	644.7 *196.5*	78.4 *23.9*	8.2	135.86 *61.61*	56.86 *25.78*	79.00 *35.83*	58.1	5	1,200	3.35 *1.52*	56.2 *28.89*	21.983 *6.700*	
	1917	LZ95 L48	5	1,970.3 *55.8*	644.7 *196.5*	78.4 *23.9*	8.2	135.86 *61.61*	54.34 *24.64*	81.52 *36.97*	60.0	5	1,200	3.35 *1.52*	58.3 *30.00*	22.967 *7.000*	
	1917	LZ100 L53	10	1,977.4 *55.8*	644.7 *196.5*	78.4 *23.9*	8.2	136.28 *61.80*	52.67 *23.88*	83.61 *37.92*	61.4	5	1,450	3.40 *1.54*	61.6 *31.67*	23.951 *7.300*	
	1917	LZ104 L59	2	2,418.7 *68.5*	743.2 *226.5*	78.4 *23.9*	9.4	166.59 *75.55*	57.69 *26.16*	108.90 *49.39*	65.4	5	1,200	3.35 *1.52*	55.6 *28.61*	26.904 *8.200*	
	1918	LZ112 L70	3	2,196.3 *62.2*	693.9 *211.5*	78.4 *23.9*	8.8	151.33 *68.63*	58.32 *26.45*	93.01 *42.18*	61.5	7	2,030	3.31 *1.50*	70.3 *36.39*	22.967 *7.000*	
	1919	LZ120 Bodensee	2	706.2 *20.0*	396.3 *120.8*	61.4 *18.7*	6.8	48.70 *22.09*	27.80 *12.61*	20.90 *9.48*	42.9	4	960	3.35 *1.52*	71.3 *36.67*		F
	1920	Bodensee, Extended		796.2 *22.6*	429.2 *130.8*	61.4 *18.7*	7.4	54.76 *24.84*	30.72 *13.94*	24.04 *10.90*	43.9	4	960	3.35 *1.52*	69.1 *35.56*		
	1924	LZ126 Los Angeles ZRIII	1	2,471.7 *70.0*	656.2 *200.0*	90.6 *27.6*	7.3	170.35 *77.26*	84.65 *38.40*	85.70 *38.86*	50.3	5	2,000	5.40 *2.45*	68.0 *35.00*		G
	1928	LZ127 Graf Zeppelin	1	3,707.6 *105.0*	776.0 *236.5*	113.2 *34.5*	7.7	255.00 *115.65*	147.95 *67.10*	107.05 *48.55*	42.0	5	2,750	4.41 *2.00*	62.1 *31.94*		H
	1935	LZ129 Hindenburg	1	6,708.9 *190.0*	803.9 *245.0*	135.2 *41.2*	6.0	459.83 *208.54*	286.65 *130.00*	173.18 *78.54*	37.7	4	4,200	4.19 *1.90*	67.5 *34.72*		L
	1938	LZ130 Graf Zeppelin II	1	6,708.9 *190.0*	803.9 *245.0*	134.5 *41.0*	6.0	459.83 *208.54*	286.65 *130.00*	173.18 *78.54*	37.7	4	4,200	4.19 *1.90*	69.1 *35.56*		
	1911	SL1	1	728.9 *20.5*	429.8 *131.0*	60.4 *18.4*	7.1	49.99 *22.67*	40.07 *18.17*	9.92 *4.50*	19.9	2	480	4.58 *2.08*	36.9 *19.00*		
	1914	SL2 (Prior to Extension)	1	882.8 *25.0*	472.5 *144.0*	59.7 *18.2*	7.9	60.97 *27.65*	43.33 *19.65*	17.64 *8.00*	28.9	4	720	6.12 *2.78*	47.6 *24.50*		
	1915	SL3	3	1,144.4 *32.4*	502.3 *153.1*	64.8 *19.8*	7.8	79.9 *35.83*	49.90 *22.63*	29.11 *13.20*	36.8	4	840	5.24 *2.38*	50.3 *25.90*		J
	1915	SL6	2	1,240.4 *35.1*	531.9 *162.1*	64.8 *19.8*	8.2	85.58 *38.81*	50.74 *23.01*	34.84 *15.80*	40.7	4	840	5.24 *2.38*	50.3 *25.90*		
	1916	SL8	10	1,369.3 *38.8*	570.9 *174.0*	65.9 *20.1*	8.7	94.62 *42.91*	48.76 *22.11*	45.86 *20.80*	48.5	4	960	4.59 *2.08*	50.3 *25.90*		
	1917	SL20	3	1,977.4 *56.0*	650.6 *198.3*	75.1 *22.9*	8.7	136.53 *61.92*	58.47 *26.52*	78.06 *35.40*	57.2	5	1,200	4.59 *2.08*	54.5 *28.06*		

Table 3–III. Characteristics of Representative Rigid Airships (Sheet 3 of 3)

				DIMENSTIONAL DATA				WEIGHT AND LIFT DATA				ENGINE DATA			*PERFORMANCE DATA*		
COUNTRY	YEAR, FIRST FLIGHT OF FIRST TYPE	TYPE AND NAME	QUANTITY BUILT	GAS VOLUME $\times 10^3$ lb *m^3*	LENGTH ft *m*	DIAMETER MAXIMUM lb *m*	FINENESS RATIO	STATIC GROSS LIFT $\times 10^3$ lb *kg*	OPERATIONAL WEIGHT EMPTY $\times 10^3$ lb *kg*	USEFUL LIFT $\times 10^3$ lb *kg*	USEFUL LIFT: GROSS LIFT %	QUANTITY	TOTAL POWER hp	WEIGHT POWER RATIO lb/hp *kg/hp*	SPEED, MAXIMUM kt *m/s*	PRESSURE ALTITUDE $\times 10^3$ ft *m*	ILLUSTR FIG. 3–4
ENGLAND	1911	R1 Mayfly	1	663.8 *18.8*	512.2 *156.1*	47.9 *14.6*	10.7	48.07 *21.80*	43.88 *19.90*	4.19 *1.90*	8.7	2	320	3.94 *1.79*	36.5 *18.80*		
	1916	R9 Class	1	889.8 *25.2*	525.9 *160.3*	53.2 *16.2*	9.9	64.39 *29.20*	59.76 *27.10*	4.63 *2.10*	7.2	4	600		39.1 *20.10*		K
	1917	R23 Class	4	997.5 *28.3*	535.1 *163.1*	53.2 *16.2*	10.1	72.34 *32.80*	59.54 *27.00*	12.80 *5.80*	17.7	4	1,200	3.92 *1.78*	47.4 *24.40*		
	1918	R23 X Class	2	990.4 *28.1*	539.1 *164.3*	53.2 *16.2*	10.1	71.88 *32.60*	55.13 *25.00*	16.75 *7.60*	23.3	4	1,200	3.92 *1.78*	49.2 *25.30*		
	1918	R31 Class	2	1,552.8 *44.0*	614.5 *187.3*	65.9 *20.1*	9.3	112.46 *51.00*	68.80 *31.20*	43.66 *19.80*	38.8	6	1,800	3.92 *1.78*	61.8 *31.80*		
	1919	R33 Class	2	1,958.3 *55.5*	643.1 *196.0*	78.7 *24.0*	8.2	142.00 *64.40*	81.36 *36.90*	60.64 *27.50*	42.7	5	1,250	4.26 *1.93*	52.1 *26.80*		
	1920	R80 Class	1	1,259.9 *35.7*	531.5 *162.0*	69.9 *21.3*	7.6	91.29 *41.40*	48.51 *22.00*	42.78 *19.40*	46.9	4	980		52.1 *26.80*		L
	1921	R36 Class	1	2,119.7 *60.0*	672.6 *205.0*	78.7 *24.0*	8.5	153.58 *69.65*	117.75 *53.40*	36.83 *16.25*	23.3	5	1,540	3.84 *1.74*	56.6 *29.10*		
	1921	R38 Class	1	2,740.1 *77.6*	694.9 *211.8*	85.3 *26.0*	8.1	198.45 *90.00*	80.92 *36.70*	117.53 *53.30*	59.2	6	2,100	3.84 *1.74*	57.3 *29.50*		
	1929	R100	1	5,157.4 *146.1*	719.9 *219.4*	132.2 *40.6*	5.4	374.19 *169.70*	235.05 *106.60*	139.14 *63.10*	37.2	6	4,020	2.02 *.92*	70.6 *36.30*		M
	1929	R101	1	4,997.8 *141.5*	731.7 *223.0*	131.6 *40.1*	5.6	362.06 *164.20*	246.52 *111.80*	115.54 *52.40*	31.9	5	2,925	7.80 *3.54*	60.8 *31.30*		

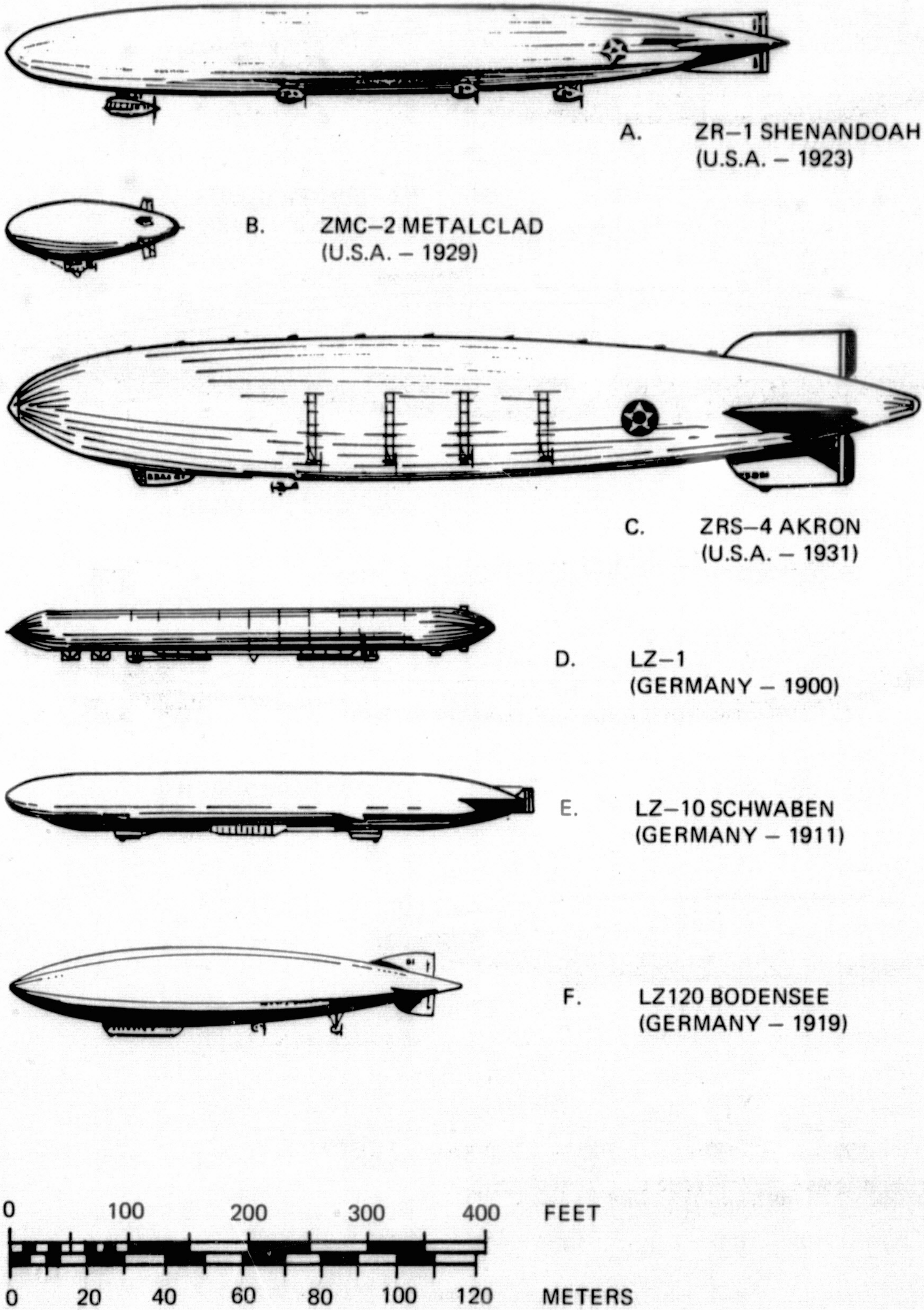
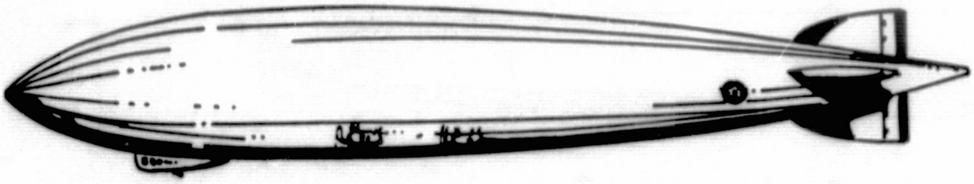
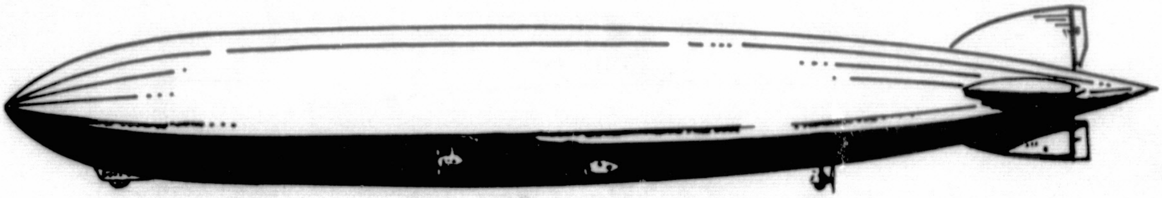


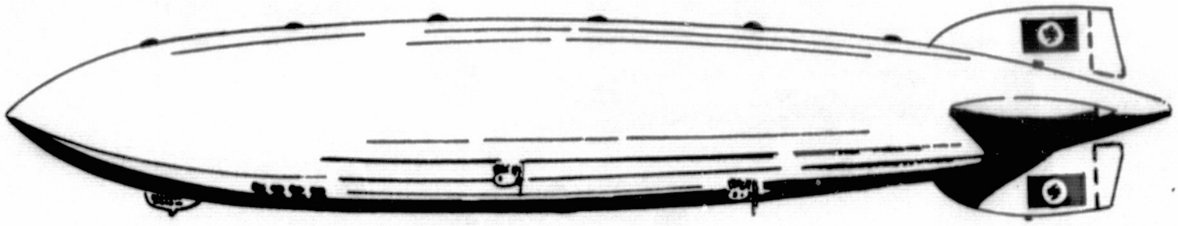
Figure 3–4. Contours of Some Rigid Airships (Sheet 1 of 3)



G. LZ–126 ZR–III LOS ANGELES
(GERMANY – 1924)



H. LZ–127 GRAF ZEPPELIN
(GERMANY – 1928)



I. LZ–129 HINDENBURG
(GERMANY – 1935)

J. SL3
(GERMANY – 1915)

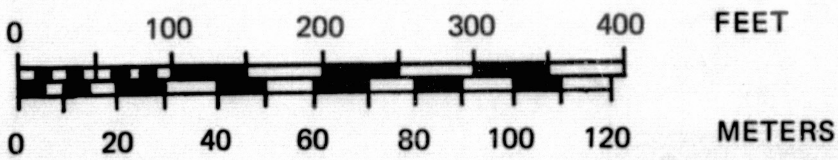
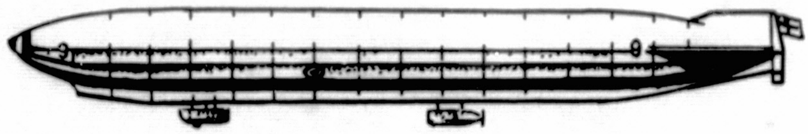
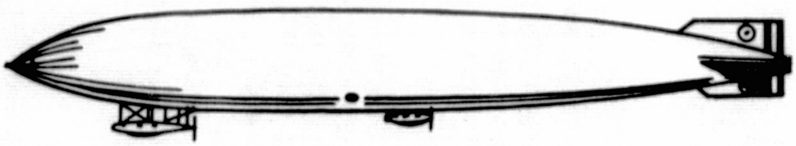


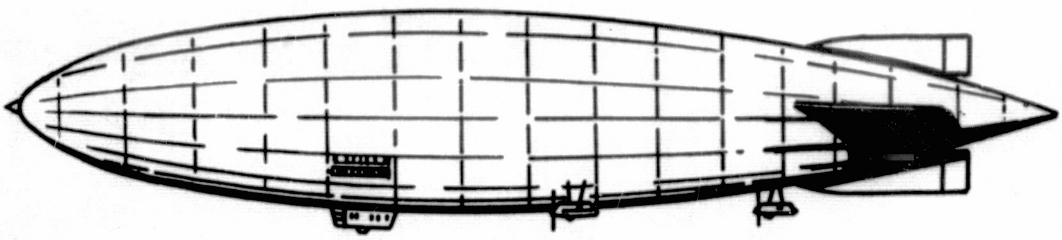
Figure 3–4. Contours of Some Rigid Airships (Sheet 2 of 3)



K. R9 CLASS
(ENGLAND – 1916)



L. R80 CLASS
(ENGLAND – 1920)



M. R100
(ENGLAND – 1929)

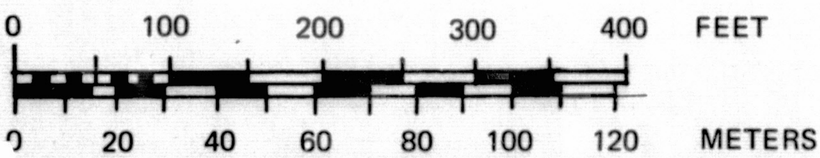


Figure 3–4. Contours of Some Rigid Airships (Sheet 3 of 3)

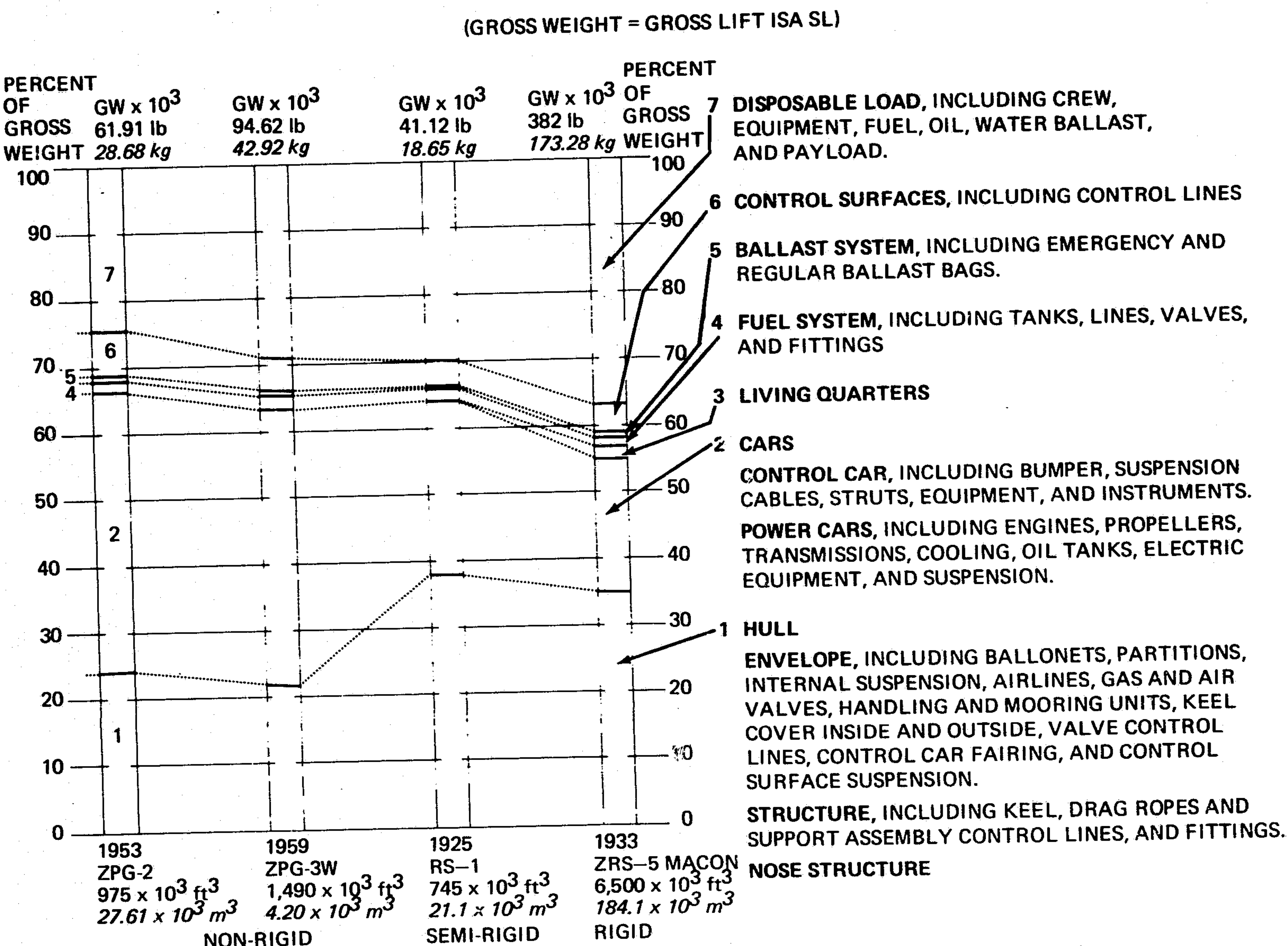


Figure 3–5 Weight Breakdown of Representative Non-Rigid, Semi-Rigid, and Rigid Airships in Percent of Gross Weight

Table 3—IV. Past Commercial Missions

AIRSHIP	YEAR	MAIN ROUTE*	NUMBER OF FLIGHTS	FLIGHT HOURS	TOTAL DISTANCE nm *km*	NUMBER OF PASSENGERS	MAIL lb *kg*	FREIGHT lb *kg*
TRANSAERIENNE I (ASTRA TYPE)	1909–1911	1	273	+	4,314 *7,990*	2,590		
7 AIRSHIPS (DELAG)	1910–1914	2	1,588	3,176	93,000 *172,535*	35,028	—	—
LZ-120 BODENSEE & NORDSTERN	1919	3	103	532	27,650 *51,258*	2,253	11,000 *5,000*	6,600 *3,000*
LZ-127 GRAF ZEPPELIN	1933–1937	4	590	17,177	914,000 *1,695,272*	13,110	86,200 *39,219*	67,000 *30,442*
LZ-129 HINDENBURG	1936–1937	5	63	3,088	182,000 *337,129*	3,059	19,550 *8,869*	21,450 *9,758*
TOTAL			2,617	23,973 +	1,220,964 *2,264,184*	56,040	116,750 *53,088*	95,050 *43,200*

NOTE: REFERENCES TO PASSENGER TRAFFIC IN U.S.S.R. HAVE BEEN SEEN, STATING THAT BEFORE WW II, 15 SMALL NON-RIGID AND SEMI-RIGID AIRSHIPS WERE IN OPERATION BETWEEN MOSCOW AND SVERDLOSK. NO FURTHER PROOF AND STATISTICS HAVE BEEN UNCOVERED.[17,38]

*MAIN ROUTE
1. PLEASURE FLYING DURING SUMMERS IN FRANCE BY THE COMPAGNIE GENERAL TRANSARIENNE
2. PLEASURE FLYING
3. FRIEDRICHSHAFEN – BERLIN
4. FRIEDRICHSHAFEN – RIO DE JANEIRO
5. FRIEDRICHSHAFEN – LAKEHURST

In 1910, the German Company DELAG (Deutsche Lutschiffahrts A.G.) founded by von Zeppelin in November 1909, inauguarated sight-seeing and pleasure flying by airship. An average of 20-24 passengers were carried and served drinks and cold platters by the world's first air steward on each flight.

After WW I, Dr. Eckener of the Zeppelin Company started regular passenger traffic between Fredrichshafen and Berlin. This operation was planned to be expanded to become the first international scheduled flight by continuing to Stockholm from Berlin.[7] These plans never materialized, however, because the two airships "Bodensee" and Nordstern" used in the traffic became a part of the reparation after WW I. Regular international airship traffic did not commence until 1933. Paying passengers were, however, carried onboard Graf Zeppelin on the around the world flight in 1929; 6,073 NM (11,247 km) with an in-flight time of 101 hours 49 minutes were covered.[7]

Another Graf Zeppelin flight worth mentioning was the participation in the "Arctic Year" in 1931. 145 hours without

refueling was flown in the Arctic taking photographs and measurements of different kinds.[7]

In connection with Arctic flights, the successful flight of the Italian constructed semi-rigid airship Norge (N-1) in April 1926 must be noted. Crossing the North Pole and landing in Alaska meant a great triumph for the airship, the Norwegian Amundsen and the Italian Nobile. In May 1928 another attempt to cross the North Pole was made by Italia, also with Nobile onboard and in charge. However, they met very severe weather before reaching the Pole. In an attempt to land, most of the crew got off, but before they could catch the landing ropes and hold down Italia, the airship took off with remaining crew members and disappeared forever.

Statistics from the past commercial operations are tabulated in Table 3-IV. The traffic on the U.S.A. and Brazil required a paying load factor of 93-98% for break even. This was seldom achieved. The traffic was heavily subsidized. The one-way fare between Germany and the Americas was approximately 500 in 1975 dollars. Most of the mail was philately mail which cost 3.80 DM per 5 grams in 1936-37; which equals $1.30 in 1975 dollars for 0.2 oz. a charge 12.5 times higher than 1975's U.S. overseas airmail rate [3,7] (26¢ for 0.5 oz.).

Commercial uses of airships today are restricted to publicity flying by Goodyear in U.S.A. and Europe and Westdeutsche Luftwerbung (WDL) in West Germany. Only small non-rigid airships are used.

3.1.2.2 Military Missions

3.1.2.2.1 World War I

Airships were used in WW I by all major nations involved in the conflict. A brief review of this use follows, without which the history of the airship and its uses is not complete.

England entered the war on 5 August 1914, and only four days after that the first scouting patrol was made by a small non-rigid airship. At the end of the war, nearly 400 non-rigid airships had been built in England and put in service. The fleet logged 83,660 flight hours and flew a distance of 2,262,160 NM (4,189,520 km). An almost continuous patrol was maintained over the water from the Scillies to Scapa Flow. At the end of the war in 1918, 103 of the airships were still in operation.[4,38]

In France, the French Army operated non-rigid airships in 1917. The army soon gave them up to the navy because of the heavy losses due to enemy fire when flying over land. (The same was experienced by the German Army which also relinquished most of its airships to the German Navy at an early stage of

the war). The French naval missions were "remarkably effective in spotting and destroying mines, in the search and attack on enemy submarines, air-sea rescue and the protection of convoys; no convoy under airship escort was ever attacked by a submarine."[4] The American Expeditionary Force had several of the French airships at their disposal. The French lost only four airships during WW I, due to accidents not caused by the enemy.

In Germany, a total of 123 airships were operated by the German Navy and Army. The navy fleet consisted of 65 Zeppelins and 9 Schütte-Lanz rigid airships, and 3 Parceval and 1 Gross-Bassenach non-rigids; a total of 78. The army had 35 Zeppelins and 10 Schütte-Lanz.[3,7] The German army gave up airships in 1916 due to heavy enemy losses. The remaining airships were given to the Navy.[38]

The small navy non-rigid airships were used to patrol the off-shore areas, spotting mines and submarines. The navy rigids were used for bombing, reconnaissance, and escort patrols over the sea. A total of 200 bombing attacks were made over England, Paris, Liege and Italian targets on the Adriatic Seacoast. The 1,145 reconnaissance and patrol missions, included assistance to the German fleet in the Black Sea, spotting convoys carrying oil and coal[4] to Bulgaria and Turkey. The German Navy lost 39 airships due to enemy action, of which 14 were shot down. The other ones made emergency landings.[3,7]

The army rigids made a total 276 bombings and long-range patrol missions over the Western, Eastern, and Balkan front. The army lost 25 of their airships, 17 of them due to enemy action.[4]

Italy had ten semi-rigid airships in army service during WW I. They flew 41,204 NM (76,308 km) in 1,400 flight hours, carried out 258 bombing raids, most of them over Austria, and naval reconnaissance flights. At least one was lost due to enemy action.[4]

The U.S. Expeditionary Forces to Europe had at their disposal probably 8 airship in England, and 10 to 14 in France.[2] U.S. Naval Aviation 1910-1960 reports for 27 April 1918: "The airship AT-1, commanded by Lt. F. P. Culbert, completed a 25-hour 43-minute flight out of Paimboeuf, France, during the course of which three convoys were escorted through a mined zone. For their flight, the longest on record for an airship of this type, the commanding officer and crew were officially commended by the French Minister of Marine."[14]

3.1.2.2.2 World War II

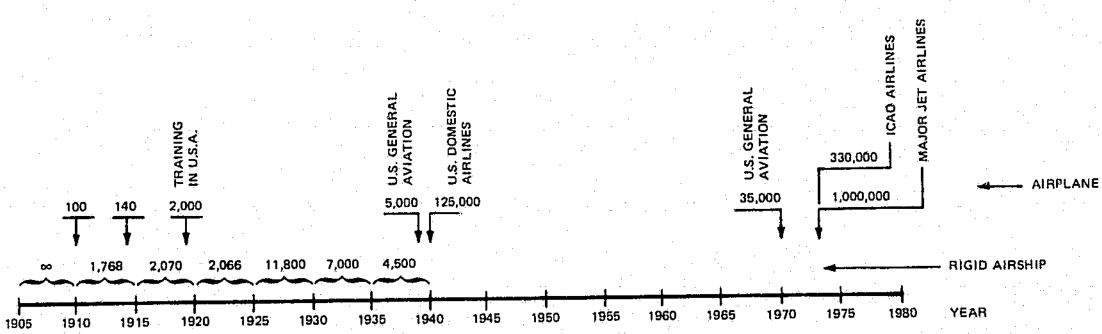
In WW II the U.S. Navy was the only service operating airships. They were of the non-rigid type. This was a very successful operation. The majority of missions were escorting of convoys over the Atlantic Ocean, providing protection for submarines and spotting mines in coastal waters.

200 airships were operated by 15 squadrons. 550,000 flight hours were flown in 55,900 missions with a remarkable operational readiness of 87%. Not one of the 89,000 escorted ships was lost to the enemy. Only one airship was lost on 18 July 1943 in a gun duel with a submarine in the Caribbean. The airship floated for hours and all the crew except for one were rescued.[8,14]

The U.S. Navy continued to develop and operate non-rigid airships for ASW and AEW missions in limited quantities up through the 1950's. The last U.S. Navy airship was decommissioned in 1962.

3.1.2.3 Safety Record

The safety of past airship operation is best illustrated by Figure 3-6, which shows flight hours per fatal accident.[3]



NOTE: LOSSES DUE TO ENEMY ACTION ARE EXCLUDED

Figure 3–6. Flight Hours per Total Accident Rigid Airships and Airplanes

The statistic for the airship is up to 1940 which is the time when devoted development of different kinds of airships ceased. The statistic for airplanes is also shown up to today. As can be seen, the airship fatal accident ratio was on a par with general aviation in the U.S. when the development stopped. Airline safety was far ahead. The safety of the airplane continued to grow by development of different subsystems to increase the reliability and by improved materials, designs and manufacturing methods. Much of this modern technology can, of course, be applied to a modern airship design and

thus boost the safety of an LTA vehicle. However, there are systems and requirements peculiar to an airship, especially in regard to structures, loads and load factors, which require separate development efforts, most probably in an accelerated manner, to assure that a modern airship when it appears can offer safety close to the present safety of airplanes.

3.2 TECHNOLOGY, 1930 vs. 1975

Although no real research and development activity regarding airships and its systems has taken place during the past 35-40 years, it does not mean that a design of a modern airships would start where the past airship technology terminated. The technological disciplines overall have made large advancements, in some areas at an explosive rate, during dormancy years of the airship. The results of these advancements are fully applicable to many airship systems including structural components. Materials, metallic as well as soft goods, have improved remarkably by better processes and dependable uniformity, new alloys, new man-made fibers for soft goods, and by the addition of composites to the field of materials, all advancements directly applicable to a modern airship.

The modern airship will also benefit from the advanced engine technology and electronic technology which has revolutionized the fields of propulsion, avionics, instruments, and automation making sophisticated systems feasible and reliable.

Another significant area of progress is the development of computerized analytic techniques for performance, sizing, and, maybe more important, for design and stressing. This makes a detailed analysis of large structures possible.

With all the technological advancements, the rebirth of the airship does not have to start, fortunately, with a copy of what was built 20-40 years ago. However, the past airship, which indeed showed some remarkable performances in the perspective of its era, should serve as a baseline from which the design of a modern airship can evolve and find its market in a completely new era more challenging with more competition in effective means of transportation than in the 1930's.

A few technological areas have been selected for a comparison to illustrate the degree of advancement. The 1930 and 1975 state-of-the-art of these areas are discussed in the following paragraphs.

3.2.1 Vehicle Performance

Sizes and performances of the 1930's airship are described in Tables 3-I, 3-II and 3-III. The range of volumes, installed power and speeds are summarized in the following Table 3-V.

Table 3–V. Range of Airship Sizes and Performances Up Through the Early 1930's

AIRSHIP TYPE	RANGE OF VOLUME X 10^3 ft^3 *m^3*	RANGE OF INSTALLED POWER hp	RANGE OF MAXIMUM SPEED kt *m/s*
NON-RIGID	35 – 300 *1 – 8.5*	40 – 600	30 – 60 *15.4 – 30.9*
SEMI-RIGID	635 – 1,240 *1.8 – 35.1*	20 – 2,100	20 – 65 *10.3 – 33.4*
RIGID	202 – 6,500 *5.7 – 184.1*	30 – 4,480	25 – 75 *12.9 – 38.6*

3.2.1.1 Altitude

High altitude airships were developed during WWI by necessity to avoid enemy fire and fixed wing fighter aircraft. Both the Italians and the Germans, using the airships in bomb raids designed some models for pressure altitudes above 20,000 ft. (6,100 m). Thus, the Zeppelin design LZ-104 in 1917 was designed for a pressure altitude of 26,900 ft. (8,200 m). (See Table 3-III). This 2.4 x 10^6 ft^3 (68.5 x 10^3 m^3) airship had a useful lift of 12,040 lb (5,461 kg) at the pressure altitude. At sea level on a ISA standard day the useful lift was almost 109,000 lb (49,000 kg). With 1,200 horsepower the sea level maximum speed was close to 56 kt (29 m/s). LZ 112 built in the following year, 1918, had seven engines totalling 2,030 hp which gave a sea level maximum speed of 70 kt (36 m/s). The pressure altitude was 23,000 ft. (7,000m) with a useful lift of 44,700 lb. (20,275 kg) at that altitude.

3.2.1.2 Speed

The speed capability was limited by available engine power and the drag. Engines were heavy and voluminous during that time period. (See Paragraph 3.2.2 Propulsion) The 1975 engine technology can give a turboprop engine of 17 times more horsepower for the same weight as the 1930's state-of-the-art. Relating to the volume, today's engine will produce almost 8 times more horsepower in the same space.

3.2.1.3 Drag

The drag of the 1930's airship is plotted in Figure 3-7 as the equivalent flat-plate drag area (f_e) as a function of the wetted surface (S_{wet}). The solid line represents a mean line for several 1930 era non-rigid and rigid airships. A 5 x $10^6 ft^3$ (.1416 x $10^3 m^2$) airship, with a wetted surface area of 182 x $10^3 ft^2$ (16.908 x $10^3 m^2$), had a f_e: S_{wet} figure of approximately 0.0033. For the same size 1975 airship with improved covering materials offering a longer lasting smooth surface, with normal attention to a drag clean surface, and designed for a speed of 50 kt (25.7 m/s), the equivalent drag plate area would decrease 8% and the f_e: S_{wet} figure would approach 0.003. A 5 x $10^6 ft^3$ (.1416 x $10^6 m^3$) rigid airship designed for 200 kt (102.9 m/s) would have a drag flat plate area approximately 80% of the 1930's 50 kt (25.7 m/s) airship.

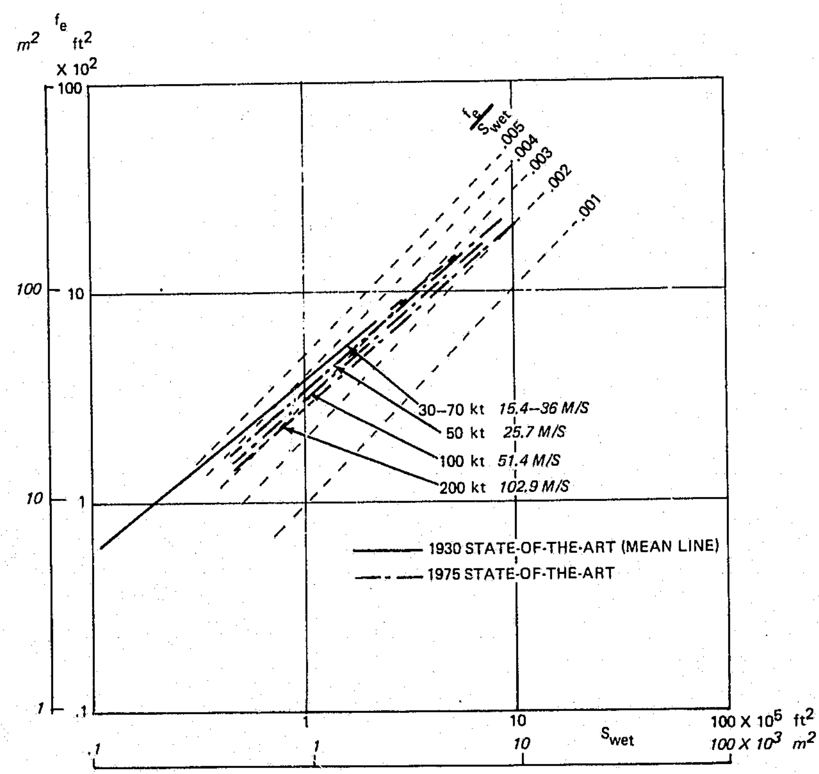


Figure 3–7. Drag Trend

A covering made from artificial fibers can be expected to keep taut and smooth for a longer time than the natural fiber fabric used in the 1930 era. In those days it was not unusual that the covering became slack in about 6 months resulting in a speed reduction of 10% or an increase in fuel consumption of 30% at a given speed.[13]

3.2.1.4 Weight

The 1930's trend curve for weight empty as a function of volume is shown in Figure 3-8 for non-rigid airships and in Figure 3-9 for rigids. The figures also show the 1975 trends.

A 1975 1×10^6 ft^3 (28.32×10^3) non-rigid airship designed for 50 kt (25.7 m/s) would have a weight empty 24% lower than its 1930th counterpart; mostly due to the tremendous improvements in soft goods material. (See Paragraph 3.2.5 Materials and Structures). A 100 kt (51.4 m/s) non-rigid would,on the other hand,be about 29% heavier than its slower 1930th match mostly due to the increased aerodynamic forces requiring higher internal pressure to rigidize the envelope, calling for heavier fabric.

Figure 3-9 shows that for a 5×10^6ft^3 ($.1416 \times 10^6$m^3) volume rigid airship of 1930th vintage, the weight empty was about 170×10^3 lb (77×10^3 kg). A 1975 counterpart would be approximately 30% lighter; if designed for 100 kt (51.4 m/s), 24% lighter. A design speed of 200 kt (102.9 m/s) requires,however,a weight empty which is close to 10% heavier than the 1930's 50 kt (25.7 m/s) rigid airship of 5×10^6 ft^3 ($.1416 \times 10^6$ m^3).

3.2.1.5 Gas Cell Permeability

In establishing the weight empty trend for the 1975 technology airships, both non-rigid and rigid, the latest advancement in materials have been considered including a permeability of 0.5 ℓ/m^2 x 24 hr x Atm. has been considered. This is also a considerable improvement from 11 ℓ/m^2 x 24 hr x Atm for the rubberized gas cells and non-rigid envelopes.[15] The goldbeater skin had a still higher leakage rate.

A flexible gelatin compound (developed by the U.S. Bureau of Standards) and applied to the rubber surface gave in laboratory tests a permeability of 0.8 ℓ/m^2 x 24 hr x Atm.[15]

The leakage of the lifting gas is not only through the material itself, in fact, the greatest loss is through seams, fittings, attachments, and pinholes in general.

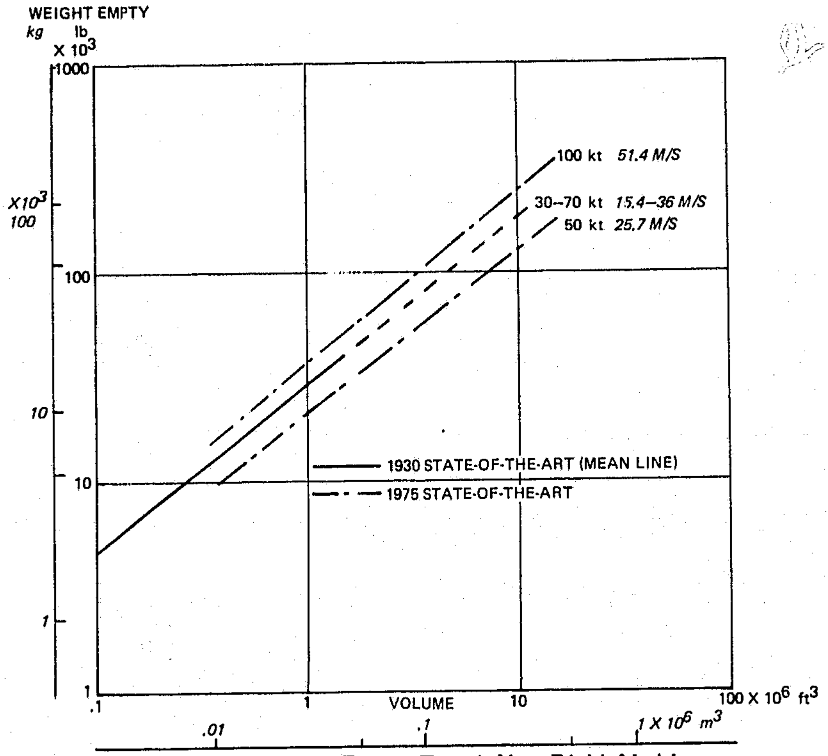


Figure 3–8. Weight Empty Trend, Non-Rigid Airships

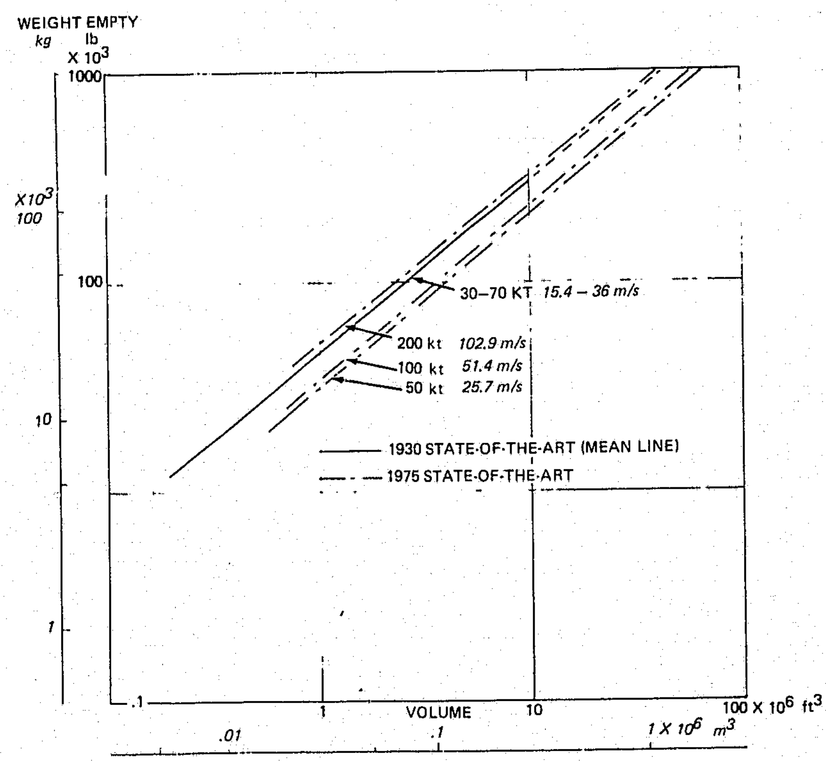


Figure 3–9. Weight Empty Trend, Rigid Airships

In 1975 small leakages can be detected by instruments not available in the past. Vitro Laboratories have designed and tested a thermal conductivity detector with a wide sweep wand which can detect and locate holes as small as 1/16 in. (1.6 mm) on large ballons filled with helium under an internal pressure of 1.5 in. (38 mm) of water.[24]

3.2.1.6 Summary

Comparing the 1930 and 1975 state-of-the-art in the area of performance, it is apparent that design for high altitudes (26,900 ft/8,200 m) were successful already in 1917. In regard to speed, the 1975 more powerful engines, but lighter and smaller (see further next paragraph 3.2.2), in conjunction with lower surface drag, can give higher speed capability. Today's artificial fiber soft goods, possibly in combination with an epoxy, offer a longer lasting smooth surface. A drag reduction, without any special boundary layer controls but with adequate attention to surface cleanness, of approximately 10% is possible.

The modern materials have an advantageous impact on weight empty. A reduction of 25-30% can be expected.

Permeability has improved more than tenfold, a condition which is important when considering today's high helium prices.

3.2.2 Propulsion

Figure 3-10 presents actual fuel consumption and installation parameters for a few representative engines in the 1930's. On the same diagram, engines of the 1975 technology are presented for a side-by-side comparison. Data on the 1975 state-of-the-art engines are taken from Paragraph 5.2.1 of this report.

The parameters selected for comparison are specific fuel consumption to represent the engine performance, and specific engine weight and engine volume to represent the design considerations.

Diesel, Rankine and Stirling cycle engines can be disregarded at this point in time. Their 1975 development status is such that they cannot meet today's requirements. (See further Paragraph 5.2.1)

A comparison between the 1930 engines and 1975 Otto and Brayton cycle engines shows that

"1975 specific fuel consumption" is about 90% of the 1930's

"1975 specific engine weight" is about 6% of the 1930's

"1975 specific volume" is about 13% of the 1930's

As can be seen, the engine technology has advanced considerably and will affect the power plant installation by the lower weight and smaller size of the engine as well as, in a smaller degree, the performance because of the lower fuel consumption. Further, higher power engines are now available with a higher reliability. Mean time between failure (MTBF) for a modern turboprop engine is more than five thousand hours.

The early installation of the engines in separate power cars outside the hull is illustrated by Figure 3-11. The Los Angeles power cars were large enough to hold two mechanics who supervised the functioning, adjusted the power setting as demanded by the engine telegraph, and also made in-flight maintenance and repairs, as required. A ladder gave access in-flight to the power cars.

A similar installation of the engines on a non-rigid airship was adopted. On smaller airships, the engine cars were attached to the gondola; on larger ones they were hung from the envelope. In the latter case, there were, for obvious reasons, no access to the engines in flight.

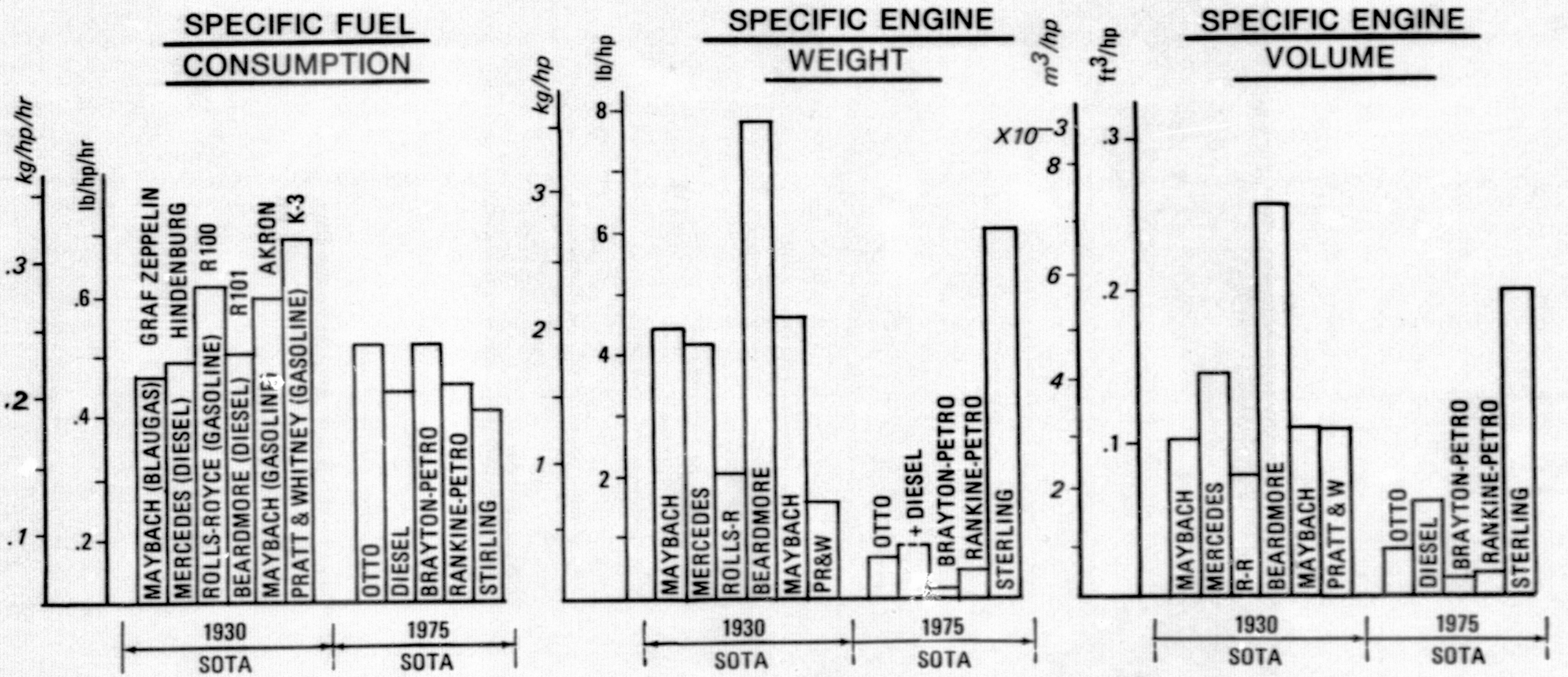


Figure 3–10. State-of-the-Art 1930 vs 1975, Typical Engines

Figure 3–11. U.S.S. Los Angeles Power Cars

The latest rigid airships had the engines installed inside the hull facing outboard and shafted to right angle gearboxes on outriggers. Figure 3-12 shows the installation in the Akron. The gearboxes could be rotated 90°; this in combination with the capability to reverse the rotation of the engine provided a capability to change the direction of the propeller thrust around the azimuth in the longitudinal direction of the airship.

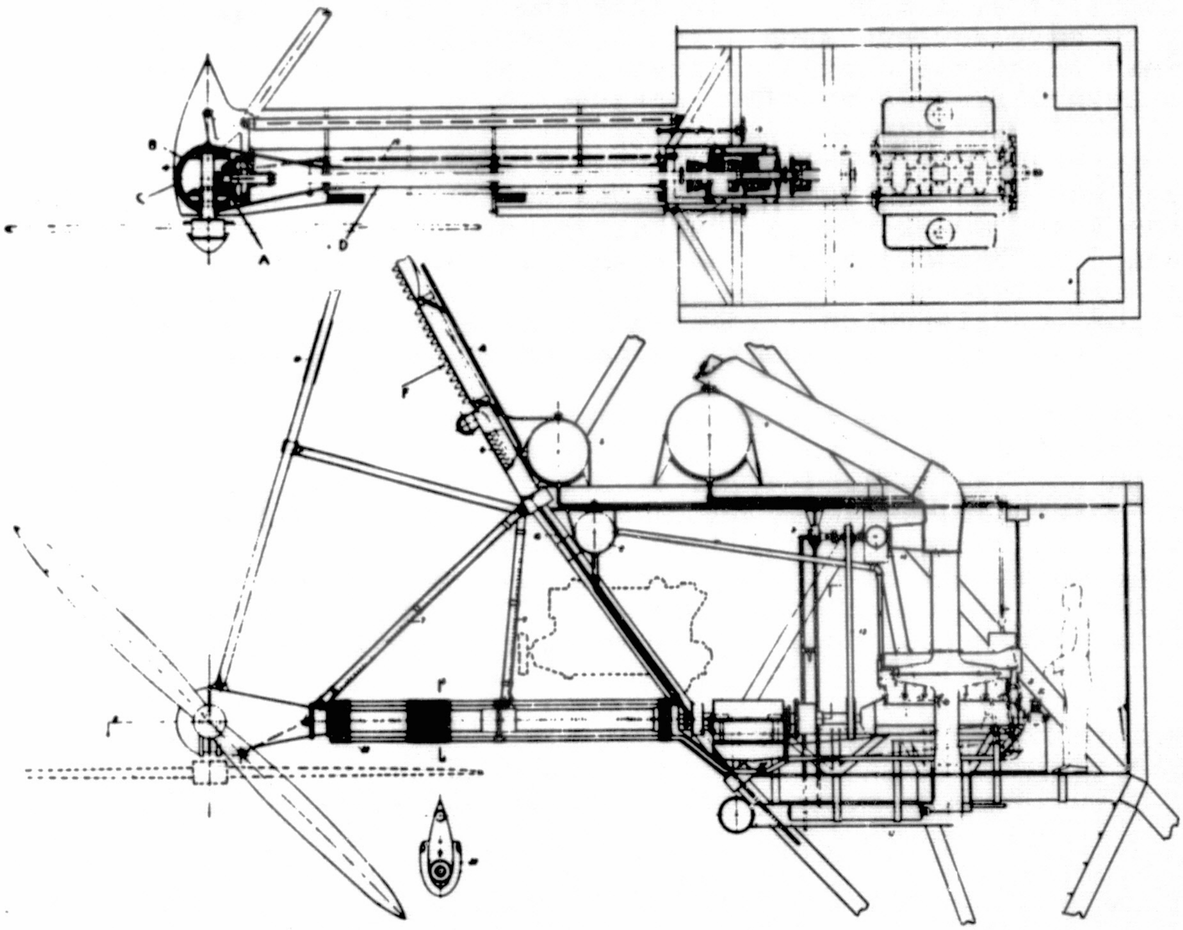


Figure 3–12. U.S.S. Akron Engine Installation

A 1975 installation of a turboprop engine would very probably be mounted on an outrigger together with gearbox and propeller. For a large airship, requiring a large amount of horsepower, the powerplant at each outrigger would probably be a twin-engine unit for the sake of redundancy and the higher efficiency at low power settings. One engine could be shut down and the remaining operated at a more efficient power level. The exact configuration of a modern powerplant arrangement must be the subject of a separate trade-off study, considering mission profile, drag of an outboard installation, weight of shafting at an inboard engine installation and complexity. It would seem at a first glance that the outboard installation may be more advantageous. The higher reliability of the modern turboprop engine does not, further, make an in-flight accessibility a worthwhile feature.

A long endurance mission requirement may make a nuclear powerplant the preferable one. (See Paragraph 5.2.1) Figure 3-13 outlines a scheme of such an installation. The nuclear reactor, located in the center of the airship, heats a fluid (helium) which is piped to turbines in the power sections. Each power section contains also a chemical fuel combustor to be used during take-off and landing. (See further Paragraph 5.2.1)

The 1975 technology offers considerable improvements in control of engines, too. Engine telegraphs, Figure 3-14, will of course, be replaced by an electronic power management system, which automatically demands power from the different engines as requested by a computer sensing the prevailing flight condition or by the pilot in the control room. A quicker response and more accurate control of the total power will result. The power management system will also monitor and control the pitch of the propellers.

A modern power management system, similar to what is being employed in today's helicopters, could offer a weight saving of up to 40% of a power control system of 1930's technology.

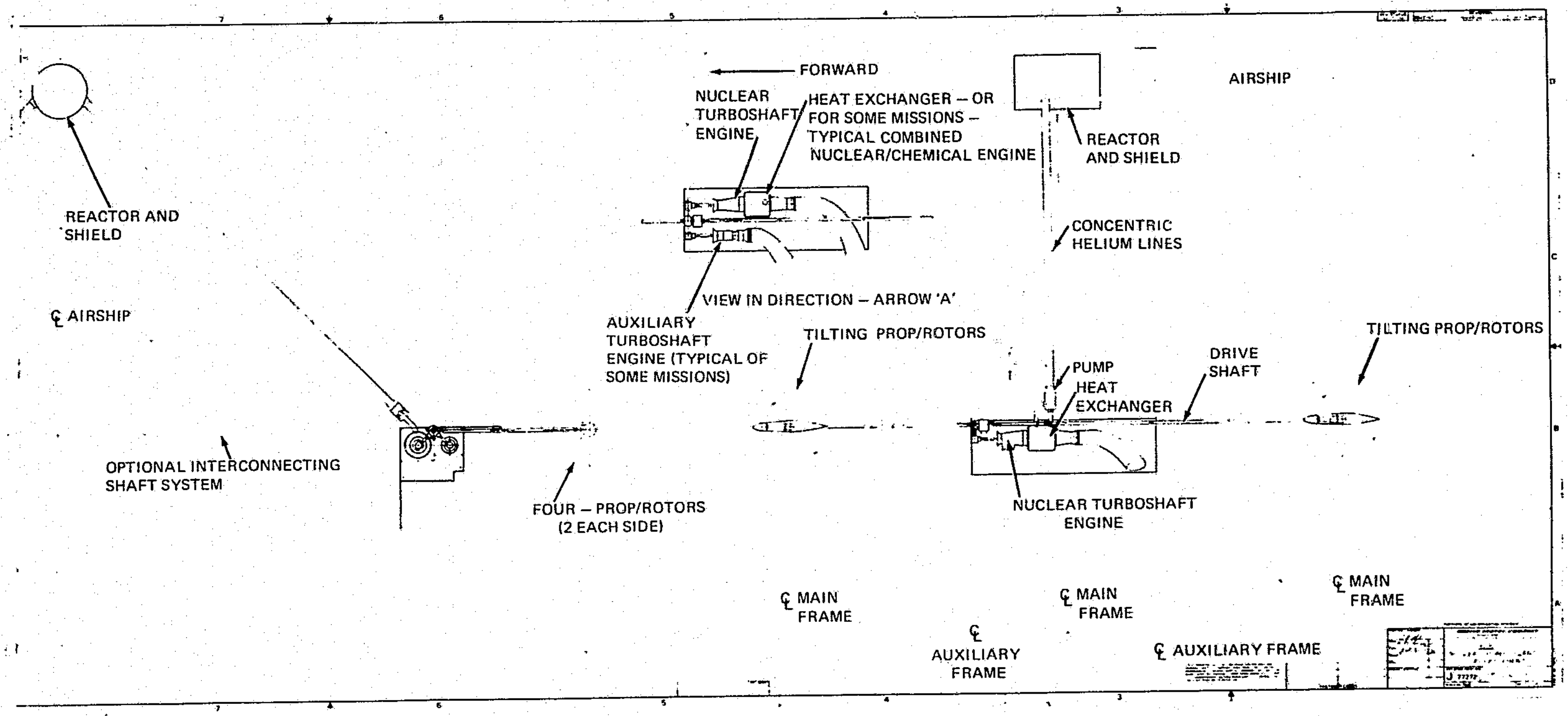


Figure 3–13. Nuclear Power Plant Propulsion

3.2.3 Avionics and Instruments

A detailed analytical comparison of the state of the art in avionics for lighter-than-air vehicles for vintage 1930 airships versus vintage 1975 airships is a more than difficult task for one very obvious reason. In 1930, avionics were almost non-existent, while in 1975 airships are almost non-existent. The few documented accounts of airships and airship operations reflect only bits and pieces of information pertaining to those functions and items of hardware normally associated with avionics. To go beyond this, one must extrapolate from similar data relative to airplanes and ships, and try to bridge the gaps of missing data by using first- and second-hand accounts of individuals who were closely associated with early avionics. All too frequently the only association these "old-timers" may have had with airships of the 1930's was to have seen one fly over as a young man.

To facilitate comparison of 1930 and 1975 avionics, it was easiest to categorize identified pieces of hardware into basic groups related to the functions provided. These are reflected in Tables 3-VI through 3-IX which are titled Engine Instruments, Flight Instruments, Communication Equipment and Navigation Equipment, respectively. Each of these sections will be discussed separately, but first some general observations are in order.

Examination of photographs of early airships such as the Los Angeles and the Macon immediately reveals that, at least as far as the control station of the typical airship is concerned, the accent is more on "ship" than on "air". Most control cabins or gondolas reflected a closer association with a ship's bridge than it did with the aircraft of that period. This is not unusual when one remembers that in some respects the behavior of an airship often more closely resembles that of a surface vessel or submarine than it does that of an airplane. The association with ships is readily evident in the engine telegraphs of Figure 3-14, the large hand valve, ship's wheel, and large nautical instruments of Figure 3-15, and the wood-framed clock and windows of Figure 3-16.

The general changes which took place in the avionics state of the art between 1930 and 1975 are best exemplified by changes which took place in the electronic communication industry during that period. Between 1930 and 1942, the industry operated with what would today be considered primitive equipment. The advent of World War II, with its attendant requirements for mobility and portability, forced the development of new technologies which began a size and weight shrinking cycle which still goes on today. By the end of World War II, the gigantic simple-element vacuum tube had given way to the miniature tube, and the subminiature tube already was under

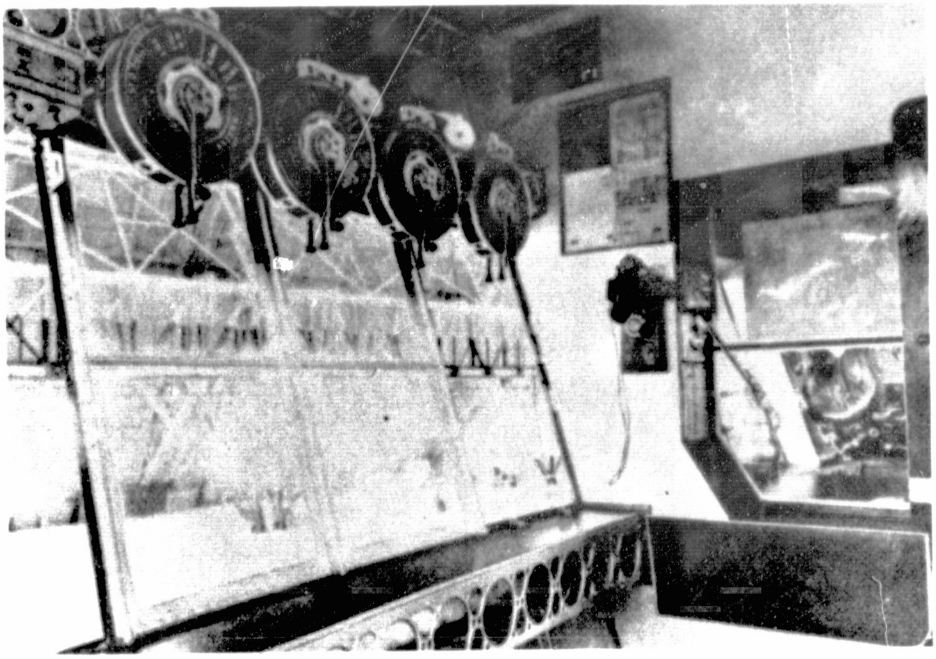


Figure 3–14. U.S.S. Macon Engine Telegraph

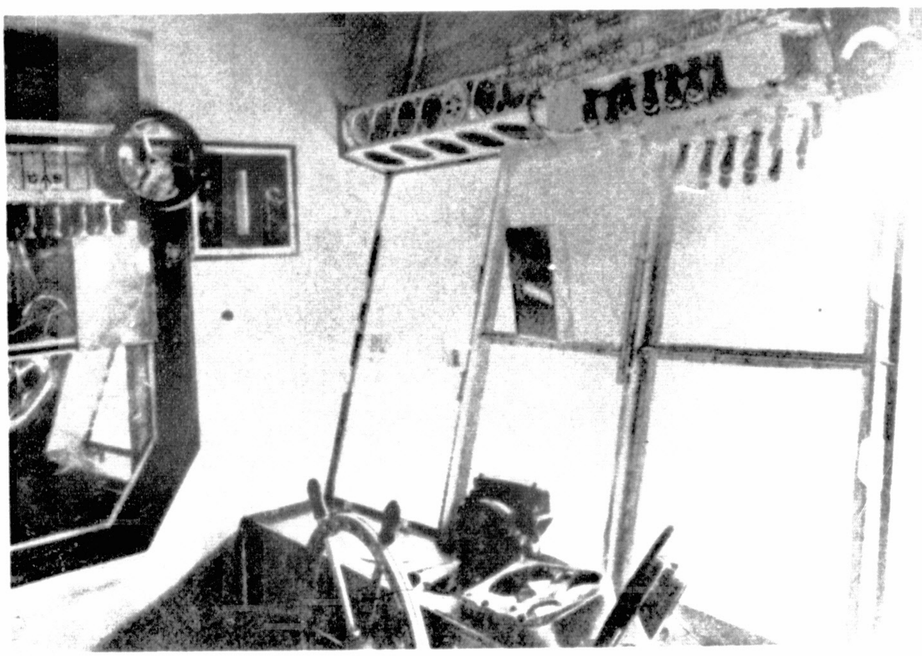


Figure 3–15. U.S.S. Macon, Port Side of Bridge

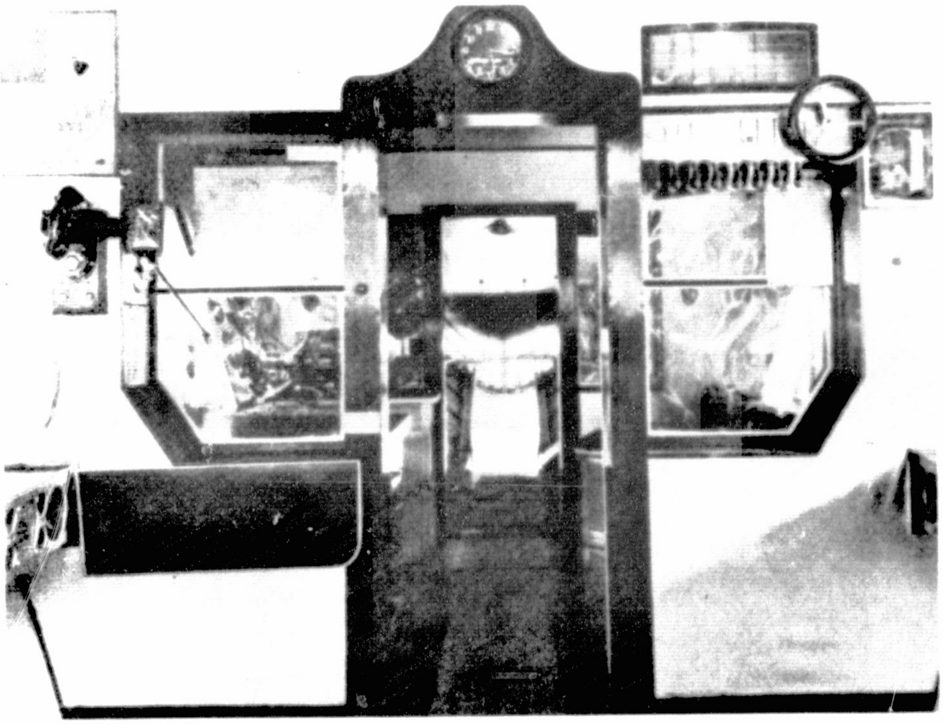


Figure 3–16. U.S.S. Macon, Looking Aft from Bridge

development. Even so, the Korean action placed further demands on greater integration with additional size and weight reduction. Shortly after the Korean action ended, the transistor and printed circuit technology made their appearances and were available for use in Southeast Asia. Under the demands for still greater performance in still smaller packages, the concepts of microelectronics and large scale integration began.

To realize the impact of this evolutionary process, one has only to examine the world of pocket calculators and realize that a scientific calculator which can be bought for less than $500 and held in one hand would probably have cost in excess of half a million dollars in 1930 and would have been housed in a cabinet larger than an office desk. In fact, at the time of this writing, one electronics component manufacturing company has just announced the development of an entire computer on a single quarter inch square chip; thus enters the age of the microprocessor.

In addition to the improvements in cost, size and weight, there also have been improvements in accuracy, performance, stability, power requirements, operational simplicity, reliability and maintainability. These will be discussed in terms of specific equipment in the sections which follow.

3.2.3.1 Engine Instruments

Engine (power plant) instruments were required in 1930 airships and would be required in a 1975 vintage airship. The power plant supplier normally would determine the best instrument suite to be used with its power plant type and design. The list in Table 3-VI is representative of such a suite for all but nuclear engines. The tachometer of 1930 was usually mechanically driven by a flexible cable in a manner similar to an automobile speedometer, where today's tachometers are driven electrically by a magnetic pickup counter or a tach generator. Engine temperatures typically are measured by thermocouples installed at critical points within the engine system. While monitoring the temperature of the engine coolant (usually water/alcohol) was a must for the 8- and 12-cylinder water cooled engines of the 1930's, no such requirement exists in today's aircooled engines. Oil temperature and pressure indicators which once brought oil lines into the cockpit now are driven remotely from electrical sensors. Fuel pressure is indicated in a manner similar to oil pressure. Fuel flow, which was indicated by the mechanical position of a metering vane in the 1930's now is indicated on a meter driven by an electrical flow sensor. Even though fuel flow technology exists, fuel flow indicators are seldom incorporated except in those vehicles, such as commercial aircraft, where fuel management is vital to the success of the operation. Fuel quantity in the 1930's was most frequently displayed via a

Table 3–VI. State-of-Art 1930 vs 1975. Typical Engine Instruments

YEAR	INSTRUMENT	TYPE	VOLUME in.^{3} *dm^3*	WEIGHT lb *kg*	POWER REQUIREMENT	ACCURACY	MTBF h	RANGE	TYPICAL COST 1975 U. S. $
1930	TACHOMETER	MARK VI	150.95 *2.47*	3.75 *1.701*	CABLE DRIVEN	±25 RPM		600–2,600 RPM	
1975		VERTICAL SCALE	107.66 *1.76*	2.85 *1.293*	3 W	±.5%	1,700	0–110%	600/CHANNEL*
1930	ENGINE TEMPERATURE	PIONEER	5.83 *.10*	.5 *.229*				–70 –150° C	
1975		VERTICAL SCALE	107.66 *1.76*	2.85 *1.293*	3 W	±1%	1,700	0–1,100° C	600/CHANNEL*
1930	COOLANT TEMPERATURE	MARK VIII	19.17 *.31*	1.25 *.567*		±2° C		50–100° C	
1975		NO EQUIVALENT							
1930	OIL TEMPERATURE	MARK I D	19.17 *.31*	1.63 *.737*		±2%		0–160° C	
1975		VERTICAL SCALE	107.66 *1.76*	2.85 *1.293*	3 W	±.5%	1,700	0–200° C	600/CHANNEL*
1930	OIL PRESSURE	MARK IX C	19.17 *.31*	1.16 *.524*		±6 lb/in^2 *±41,369 N/m^2*		0–100 lb/in^2 *0–689,476 N/m^2*	
1975		VERTICAL SCALE	107.66 *1.76*	2.85 *1.293*	3 W	±.5%	1,700	0–130 lb/in^2 *0–896,319 N/m^2*	600/CHANNEL*
1930	FUEL PRESSURE	MARK VII B	19.45 *.32*	.5 *.229*		±.8 lb/in^2 *±5,516 N/m^2*		0–10 lb/in^2 *0–68,948 N/m^2*	
1975		VERTICAL SCALE	107.66 *1.76*	2.85 *1.293*	3 W	±.5%	1,700	0–50 lb/in^2 *0–344,738 N/m^2*	600/CHANNEL*
1930	FUEL FLOW	MARK II D	13.67 *.22*	.94 *.425*		±1%		5 Imp. gl/h – FULL FLOW *0.006 l/s – FULL FLOW*	
1975		VERTICAL SCALE	107.66 *1.76*	2.85 *1.293*	3 W	±.5%	1,700	0–5,000 lb/h *0–.63 kg/s*	600/CHANNEL*
1930	FUEL QUANTITY	TELEVEL 1 D	49.48 *.81*	3.25 *1.474*					
1975		GULL 202–007E00	6.30 *.43*	1.4 *.635*	28 VDC	±1.5%	675	0–6,000 lb *0–2,720 kg*	1,250

* A ROUND DIAL INDICATOR COSTS APPROXIMATE $70 to $170 PER CHANNEL

sight gage or a float indicator. With today's multiple tank/multiple engine configurations and the capability of feeding fuel from any tank to any engine it has become necessary to employ a more sophisticated fuel quantity indicating system which indicates at the minimum the amount of fuel in each fuel cell and the total fuel on board (totalizer).

For the comparisons of Table 3-VI the 1930 data considered the Mark ( ) series of British Aircraft instruments and a few Pioneer instruments (American) from the same time frame. The 1975 vintage instruments, with the exception of the fuel quantity indicating systems, are based primarily on the vertical scale instruments of the types currently built by Bendix, General Electric, Gull Airborne Instruments and others for military application. The fuel quantity system is typical of those designed for installation in 1970 vintage aircraft.

Engine instruments of the 1930's featured large dial faces, often 5-6 in.(127-152 mm) or more, but were relatively shallow in depth, thus resulting in a volume of 40 - 50 in.^{3} (655 - 550 cm^3). Instruments of the 1975 vintage have smaller faces (3 in.(76mm) or less), but considerably greater depth (often 10 in. - 12 in.) (254-305mm) thus resulting in volumes of 100 in.^{3} (1639 cm^3) or more. Despite the size difference, 1975 instruments weigh only about 2 lb (.9 kg) per channel of information as opposed to a 1930 weight of 1.5 pounds (.7 kg) per channel. The increase is primarily due to the use of synchros, torquers and similar electrical motors instead of the older bellows, bourdon tubes, and gear trains. The conversion from mechanical to electrical instruments also has resulted in introducing a power requirement for driving the electrical instruments. Typical instrument electrical power requirements are 3 watts per channel. Accuracies of the 1930 instrument ran in the neighborhood of 3% of full scale or worse, while the 1975 instruments run 1% or better. MTBF's for 1930 could not be determined, but 1500 hrs. is a typical value for 1975. Finally, there were no cost data on the 1930 engine instruments, but it is estimated that in 1975 dollars they would cost the same as today's round dial instruments, about $70 - 170 per channel. This compares with $600 per channel for vertical scale instruments.

In conclusion, the only apparent gain in 1975 engine instruments over 1930 engine instruments is an increase in accuracy from about 3% to 1%. The state of the art in engine instruments is adequate to support LTA development. In cases where two or less engines are involved, conventional round dial instruments should be used. In cases where more than two engines are used, trade studies should be conducted to determine if the advantages to be gained from the use of vertical scale instruments will render them more cost effective than multiple round dial instruments.

3.2.3.2 Flight Instruments

A comparison of 1930 and 1975 flight instruments would follow pretty much along the same lines as engine instruments. However, the specification of the flight instruments probably would be the responsibility of the procuring activity or the prime manufacturer, rather than that of a subsystem vendor. The list of Table 3-VII is representative of the suite of aircraft and airship flight instruments of both 1930 and 1975. Airships of the 1930's had several types of airspeed sensing systems available: (1) the pitot system, as we know it today, (2) the venturi, which worked on decreased pressure rather than impact pressure, (3) the vane, which was nothing more than deflection against a known force, (4) the windmill, which was a small generator driven by airflow across its propeller, and (5) a standard Robinson cup anemometer, of the type used today by weather stations to measure surface wind speeds. Of these, the pitot system is the only one still in common use in aircraft. It is the basis for most modern airspeed systems. However, the need for an airspeed indicator in airships is questionable. Airspeed indicators are used in two respects; (1) to determine calibrated or equivalent airspeed which can be used as an indication of performance of air-foil-type lifting surfaces and (2) to determine true airspeed, which in turn can be used in conjunction with wind information for navigation purposes. If the airship were "dirigible-shaped" with airfoil surfaces used for control rather than lift, an airspeed indicator would not be needed for the first reason. Since there are better techniques available for determining ground speed (such as doppler, etc.) than the method mentioned above, airspeed would be of value only in determining wind. A barometric altimeter was necessary in 1930 airships and still is in modern aircraft. It not only is used for the monitoring and controlling of air traffic flight levels for clearance purposes, but also would be very important in LTA vehicles as an indicator of barometric pressure which would affect the relationship of gas pressures internal to the airship with those of the surrounding environment. Today, encoding altimeters are required to assure compliance with air traffic control regulations. Determination of absolute altitude was as important to airships of the 1930's as it is to modern aircraft. The conventional techniques in the 1930 airship were to use the eyeball to estimate absolute altitude under day visual conditions and to triangulate on a searchlight beam projected onto the ground under night visual conditions, particularly over water. For non-visual instrument conditions, the trend was again toward the nautical, and sounding lines were used often to determine the height above the terrain. In modern day systems a radar altimeter is used for all conditions. Static air temperature was important to 1930 airships, as it is to present day aircraft, but for different reasons. Then the concern was for the relationships of contained gases and their expansion/

Table 3–VII. State-of-the-Art 1930 vs 1975. Typical Flight Instruments (Sheet 1 of 2)

INSTRUMENT	YEAR	TYPE	VOLUME in.^{3} *dm^3*	WEIGHT lb *kg*	POWER REQUIREMENT	ACCURACY	MTBF *h*	RANGE	TYPICAL COST 1975 U.S. $
AIRSPEED (PITOT)	1930	MARK IX B	40.64 *.67*	1.44 *.20*	NONE	±3 kt *±.8 m/s*		35–140 kt *9.7–38.9 m/s*	
	1975	MS 28021–4	21.95 *.35*	1.0 *.45*	NONE	±2 kt *±56 m/s*	772	20–250 kt *5.5–69.5 m/s*	215
AIRSPEED (WIND TURBINE)	1930	BUREAU OF STANDARDS	IND: 98.18 *1.61* FISH: 1.32 *2.16*	2.88 *.40* 4.25 *1.93*	NONE				
	1975	NO EQUIVALENT							
PITOT STATIC PROBE	1930	MARK VI	354.34 *5.81*	.75 *.34*	NONE				
	1975	AN5813–2	12.29 *.20*	2.00 *.91*	115 VAC		1,070		50
ALTIMETER, BAROMETRIC	1930	MARK IX D	49.99 *.82*	2.00 *.91*	NONE	± 50 ft *± 15 m*		–1,000 –40,000 ft *– 300 –12,200 m*	
	1975	AAU–21	85.56 *1.40*	3.80 *1.73*	1W @ 28 VDC 15 VA @ 115 VAC	±50 ft @ 0 ft *±15 M @ 0 m* ±200 ft @ 35,000 ft *±60 M @ 11,000 m*	7,289	–1,000 –38,000 ft *–300 –11,600 m*	
ALTIMETER, ABSOLUTE	1930	SOUNDING LINE & SEARCHLIGHT							
	1975	RADAR ALT AN/APN–194	196.65 *3.22*	7.5 *3.40*	45 VA @ 115 VAC 10 W @ 28 VDC 2.5 VA @ 5 VAC	±3 ft OR 4% *±9 m OR 4%*	1,500		5,500
AIR TEMPERATURE	1930	MARK IA	100.00 *1.64*	7.25 *3.29*	NONE	±.3° F *±.17° C*		–30 –130° F *–34 –54° C*	
	1975	MS 28028–1	13.45 *.22*	.18 *.08*	NONE	±.9° F *±.5° C*	4,975	–94 –122° F *–70 –50° C*	22
INCLINOMETER	1930	MARK VIII	10.38 *.17*	.38 *.17*	NONE	±.5° @ 0° ±2° @ 20°	∞	±20°	
	1975	BOEING VERTOL AO5E2104	21.4 *.35*	.27 *.12*	NONE		∞	0 –40°	
TURN AND BANK	1930	PIONEER	36.77 *.60*	1.20 *.54*					
	1975	INCLUDED IN ATTITUDE INDICATOR							

Table 3–VII. State-of-the-Art 1930 vs 1975 Typical Flight Instruments (Sheet 2 of 2)

INSTRUMENT	YEAR	TYPE	VOLUME in^3 *dm^3*	WEIGHT lb *kg*	POWER REQUIREMENT	ACCURACY	MTBF h	RANGE	TYPICAL COST 1975 U.S. $
ATTITUDE	1930	PIONEER	97.39 *1.60*						
	1975	ARU–18	203.44 *3.33*	5.50 *2.49*	26 VA @ 115 VAC	±.25°	750		2,080
ACCELEROMETER	1930	KOLLSMAN	23.93 *.39*						
	1975	MS 28025 B	20.00 *.33*	1.5 *.68*		±.5 g	2,610		100
CLOCK	1930	KOLLSMAN	3.91 *.06*						
	1975	MS 28020	8.50 *.14*	.75 *.34*	STEM WOUND	±30 sec/24 h	745		30
VARIOMETER	1930	KOLLSMAN	31.61 *.52*	.63 *.28*					
	1975	MS 28049–2	52.92 *.83*	1.75 *.79*		±100ft/m @ 500 ft/m *±5m/s @ 2.5 m/s* ±500 ft/m @ 5,000 ft/m *±2.5 m/s @ 25 m/s*	3,759	0–6,000 ft/m *0–30 m/s*	

contraction with respect to the environment. Today the concern is with the effect of temperature on air density and the associated aerodynamic performance. While there were cockpit air temperature indicators in the 1930's, the static air thermometer frequently was a 2 ft long standard mercury thermometer strapped to a landing gear strut and viewed through the windows of the control cab. A bubble type inclinometer was vital to the 1930 airship and would be today, although they have not been used in aircraft since about 1960 when they were used to indicate towing attitude in helicopters. The turn and bank indicator has remained relatively unchanged in operation since 1930, although today it is common practice to integrate this indicator. Attitude indicators were available in the 1930's, as they are today, but would be of questionable use in an LTA vehicle because the attitude changes are relatively small. Pitch and roll attitudes probably could be indicated best by a pair of orthogonally mounted inclinometers. A similar situation is true with accelerometers. While they were available in the 1930's for aviation use, the application is limited to vehicles having acceleration capabilities and g - forces significantly higher than those of an airship. Clocks were required in 1930 airships as they are in modern aircraft. It is interesting to note that even though smaller aircraft clocks were available in 1930, the airship crew stations reflected the nautical influence and used a much larger and heavier ship's clock. (Figure 3-16) The variometer, or rate of climb, was used in 1930 and still is used today.

For the comparison of Table 3-VII the 1930 data considered not only the British Mark ( ) series, but also the better known American instruments made by companies such as Pioneer and Kollsman. These companies are still flourishing today and the instruments they produced in 1930 are so basic to aeronautics that many of them exist today, in refined form, as Military Standard (MS) configurations.

Flight instruments of the 1975 time frame require 1/2 to 2/3 the volume of the 1930 flight instruments due to more compact design. In addition, more functions are integrated together into a single instrument, which again contributes to compactness. Consequently they are generally less volumetric (say 50 in.^{3} - 820 cm^3) than comparable engine and subsystems instruments. As in the case of engine instruments, the 1930 instruments weighed almost 1.5 lbs (.7 kg) while the 1975 instruments weight 2 - 2.5 lbs (.9-1.1 kg) for a single parameter instrument. Again the increase is primarily due to the use of electrical/electronic components and mechanical devices. Power requirements have gone from essentially none in the 1930 flight instruments to typical values of 5 watts at 28 VDC and 20-25 VA of 115 VAC for servo driven instruments. Accuracies have improved from almost 5% of full scale in 1930 to 2% of full scale today. Again MTBF's for 1930 could not be determined, but values in

excess of 2500 hrs are common today. Instrument costs today for simple instruments are comparable or cheaper than their 1930 equivalents, and run in the neighborhood of less than $100 each. However, more sophisticated flight instruments, such as attitude gyros, flight directors and radar altimeters, which were non-existent in the 1930's today cost several thousand dollars.

3.2.3.3 Communication Equipment

Unlike aviation instruments, communication equipment has undergone some significant changes between 1930 and 1975. There has always been a need for intercommunication between crew members. While direct face-to-face communication always has been the most effective, the distance between crew stations and the noise levels at crew stations has generated a need for something more effective than shouting. In 1930 the gosport and the engine telegraph were standard, and with the advent of the dial telephone modern airship intercommunications' systems began. Similar pushbutton systems are available today at far less weight (2 lbs (.9 kg) per station). Power consumption is typically 5 watts per station and cost is typically $200 per station. The MTBF of most ICS systems is very good, usually in excess of 20,000 hours.

Radio communications, such as those shown in Table 3-VII, have shown their most significant change in the frequency bands being used. While 1930 radio communications were limited to medium frequency (MF) and high frequency (HF) operations covering the frequency spectrum of 2 to 9 MHz, similar 1975 equipment, such as the HF/SSB covers the frequency spectrum 2 to 30 MHz. In addition VHF-AM, VHF-FM and UHF-AM expand the spectrum to 400 MHz. Of course, these equipments were not available in 1930.

Much of the aviation radio equipment in the 1930's was connected or modified amateur (HAM) radio equipment. There are recorded accounts in 1930 of short-wave radio experiments in which over water ranges of 200 miles (322 km) were achieved at altitudes of 12000 feet (3,658 m) by judicious selection of the proper operating band. In 1975, the MF radio is no longer in use for airborne communication. It is interesting to note that the HF-SSB of 1975 is about the same size as the 1930 set but only about 40% of the weight. A typical system of the 1930's consumed less power (approximately 400 watts) to achieve its 200 watts of transmitted energy than does the new HF/SSB which uses 1500 W input power to achieve its 400 watt output. However, it also should be noted that while the 1930 HF radios spoke of only two channels of communication, the newest HF-SSB systems boast 280,000 channels. In addition the new systems have MTBF's in the order of 1200 hours, while old timers in the radio business tell of how no radioman would go on board

Table 3–VIII. State-of-the-Art 1930 vs 1975. Typical Communication Equipment

EQUIPMENT	YEAR	TYPE	VOLUME in.^{3} *dm^3*	WEIGHT lb kg	POWER REQUIREMENT	POWER OUTPUT *W*	MTBF h	FREQUENCY	COMMENTS	TYPICAL COST 1975 & U.S. $
ICS	1930	DIAL TELEPHONE, GOSPORT, ENGINE TELEGRAPH								
	1975	C–6533/AIC	CONTROL BOX: 82.86 *1.36*	2.00 *.907*	5 W @ 28 VDC		20,000			200/STN
MF TRANSMITTER	1930	RCA AVT–12	2,355.34 *38.60*	70.00 *31.752*	50 W			2.–6.5 MHz	ALSO USED FOR SHORE – BORNE DIRECTIONAL FINDER	
	1975	NO EQUIVALENT								
HF STATION TRANSMITTER AND RECEIVER	1930	RCA AVT–7 & RCA AVR–7	1,976.20 *32.39*	100.00 *45.36*	8–33 A @ 12 VDC	200		7–9 MHz	RANGE: 200 NM at 12,000 ft altitude	
HF STATION SSB	1975	LC/ARC–400	2,074.6 *33.99*	39.00 *17.69*	(R) 36. 4W @ 28 VDC (T) 1,500 W @ *28 VDC*	400	1,200	2–30 MHz		25,000 (EST)
VHF–AM	1930	NO EQUIVALENT								
	1975	AN/ARC–115	193.70 *3.17*	7.9 *3.58*	85 W @ 28 VDC	10	660	116–149.975 MHz		1,250
VHF–FM	1930	NO EQUIVALENT								
	1975	AN/ARC–114	165.29 *2.71*	11.6 *5.26*	85 W @ 28 VDC	10	660	30–75.95 MHz		1,345
UHF–AM	1980	NO EQUIVALENT								
	1975	AN/ARC–116	193.70 *3.17*	9.1 *4.13*	85 W @ 28 VDC	10	1,000	225–399.95 MHz		1,300
IFF	1930	NO EQUIVALENT								
	1975	AN/APX–72	1,219.99 *20.00*	37.5 *17.01*	56 W @ 28 VDC 1.19 A @ 115 VAC	250 (Pulse)	300			5,000

his aircraft without a pocket full of tubes and a reasonable assurance that at least one tube would have to be replaced before the flight was over. In addition, drifting or frequency instability was a common problem in the 1930's set, whereas frequency stability in the 1975 sets is advertised at 5×10^{-7}. Because of the increase in stability, tuning time has gone from more than a minute down to one second. All of these advances have brought the cost of the 1974 HF-SSB set to a figure in excess of $5000 compared to several hundred dollars for the 1930 equipment.

The newer radios in the 30-400 MHz band are much smaller and lighter (typically 200 $in.^3$ (3278 cm^3) and 10 lb (4.5 kg), about one-tenth the size and weight of the HF equipment. Power input is typically 85 watts for a 10 watt output. The MTBF's are typically 700-800 hours and costs are about $1300.

Finally, though not included in the 1930 communication equipment complement, it is expected that some sort of identification transponder will be required for both domestic operations in congested areas and for international operations. A typical military transponder occupies 1200 $in.^3$ (19.7 dm^3) and weighs 37.5 lb (17 kg). It consumes approximately 200 watts in producing its 250 watt pulses. A typical MTBF is only 300 hours and the cost is about $5000.

3.2.3.4 Navigation Equipment

Table 3-IX shows an assortment of navigation equipment representative of that in use on modern long-range aircraft and helicopters. In 1930, only a few of these had been invented. Consequently, in visual conditions over land, navigation was done primarily by pilotage. Over water, where there were no landmarks, or during instrument flight, navigation was primarily accomplished by dead reckoning. Although there were a few radio beacons, most navigation fixes were visual, with direction finding used to check the dead reckoning when such equipment was available. Dead reckoning in 1930, as in 1975, was determined as a function of time, ground speed and track angle. Time is determined easily from a clock as described earlier under flight instruments. Ground speed and track angle were calculated as the vector sum of airspeed/heading and wind direction/speed. This could be done rather simply over land by observing a landmark through an inexpensive driftmeter. By observing the motion of the landmark relative to the driftmeter, the air vehicle's speed and track angle over the ground could be determined. At night and over water, where there were no landmarks to observe, phosphorous or calcium carbide flares had to be carried for sighting. Flares which would burn long enough for accurate sightings could weigh as much as 16 lb (7.3 kg). Today, a doppler navigation system is used which measures ground speed and drift angle directly, day or night,

Table 3-IX. State-of-the-Art 1930 vs 1975. Typical Navigation Equipment

EQUIPMENT	YEAR	TYPE	VOLUME in³ *d m³*	WEIGHT lb kg	POWER REQUIREMENT	ACCURACY	MTBF h	TYPICAL COST 1975 U.S. $
GROUND SPEED AND DRIFT ANGLE	1930	PIONEER	105.64 *1.73*	5.75 *2.61*	NOTE: FOR NIGHT AND OVER WATER REQUIRES FLARES: 403.65 in.³ *6.62 d m³, 16 lb 7.26 kg*			
	1975	DOPPLER SKD2100	757.09 *12.4*	28.6 *12.97*	26 W @ 28 VDC 43.6 W @ 28 VDC	15% GRND SPD ± .1 kt ± .05 m/s	4,845	18,000
MAGNETIC COMPASS	1930	R.O. 3	272.36 *4.46*	5.75 *2.61*				
	1975	AN5766–T4	17.28 *.28*	.8 *.36*	28 VDC (LIGHTING)	±2°	3,030	200
GYRO COMPASS	1930			120.0 *54.43*				
	1975	AN/ASN–110	858.51 *14.07*	32.50 *14.74*	1 A @ *115 V 3 ph*	.25°/h	1,600	9,300
LF/ADF	1930	FISHER–COULTER RADIO COMPASS						
	1975	AN/ARN–89	751.26 *12.31*	12.2 *5.53*	34 W @ 28 VDC		700	2,180
CELESTIAL	1930	PLATH SEXTANT			0		∞	
	1975	ASTROCOMPASS KOLLSMAN 1471C–02	1,087.00 *17.82*	12.50 *5.67*	28 VDC			19,500
UHF–DF	1930	NO EQUIVALENT						
	1975	AN/ARA–50	884.39 *14.50*	20.5 *9.30*	10 W @ 28 VDC 35 VA @ 115 VAC 10 VA @ 26 VAC	±5°	1,000	3,000
MARKER BEACON, GLIDE SLOPE AND GND STATION LOCALIZER	1930	NO EQUIVALENT						
	1975	AN/ARN–108	256.59 *4.21*	9.0 *4.08*	45 W @ 28 VDC	±1° BRG ±3 μ A ILS	1,000	3,750
RADAR	1930	NO EQUIVALENT						
	1975	AN/APN–158	4,228.15 *69.30*	54.6 *24.77*	160 VA @ 115 V 3 PH 325 VA @ 115 VAC (20,000 W PEP)			11,750
TACAN	1930	NO EQUIVALENT						
	1975	AN/ARN–504	2,163.15 *35.45*	44.7 *20.28*	575 VA @ 115 VAC 140 W @ 28 VDC	DIST: ±.15 NM *±278 m* BRNG: ±2.5°	500	
LORAN	1930	NO EQUIVALENT						
	1975		463.29 *7.59*	18.2 *8.26*	200 W @ 28 VDC		500	25,400
INERTIAL NAVIGATION	1930	NO EQUIVALENT						
	1975	CAROUSEL IV	2,224.71 *36.46*	79.06 *35.86*	30 W @ 28 VDC 1,725 VA @ 115 VAC 2 VA @ 5 VAC	1 NM/h CEP 1,852 m/h CEP	930	125,000
OMEGA	1930	NO EQUIVALENT						
	1975	AN/ARN–99 (V)2	2,980.00 *48.84*	85.20 *38.64*	61 VA @ 115 VAC 55 W @ 28 VDC 1.5A @ 5 VAC	1.4 NM *2,593 m*	1,500	

over land or sea. While with its antenna it is 5-7 times as large and heavy as a driftmeter and requires 40-50 watts of power, its typical accuracy of .15% of ground speed or .1 knot (.05 m/s) (whichever is greater) and its MTBF of about 4800 hours are reasons for its use on many modern aircraft. Typical cost of a doppler navigator is $18,000-$20,000.

Both the driftmeter and the doppler navigator depend on accurate heading information if an accurate track angle is to be determined. In 1930, the most popular source of heading in airships was the nautical type compass which occupied a volume of more than 250 in.^{3} (4.098 cm^3) and weighed about 6 lb (2.7 kg). Today, the "wet" compass takes up less than 20 in.^{3} (328 cm^3) and weighs less than 1 lb (.45 kg) including lighting. Its accuracy is about ±2° and its MTBF about 300 hours. Typical cost is $200. A better source of heading information is a gyro compass. These were available in the 1930's for those vehicles which could accept the 120 lb (54.4 kg) weight penalty which came with them. Today, a three-axis gyro system having a .25°/hr. free gyro drift rate will weigh only 30-35 lb (13.6-15.9 kg) and occupy about .5 ft^3 (14.2 dm^3). A typical MTBF is 1600 hrs. and cost will be between $9,000 and $10,000.

Little information could be found about the use of the Fisher-Coulter radio compass, except that it became available in about the late 1930's and from available photographs, it appears that the loop antenna housing was about 1/2 the size of a bath-tub. Today a typical ADF will occupy 0.5 ft^3 (14.2 dm^3) consume 35 W of power, have an MTBF of about 700 hours and cost a little more than $2000. The present UHF/DF, for which there was no 1930 equivalent, is about the same size as the LF/ADF, weighs about 20 lb, (9.1 kg) consumes about the same power, has a slightly higher MTBF of 1000 hours and costs about $3000.

Another available navigation device of the 1930's was the sextant, which was used for celestial navigation. Its 1975 equivalent, the sophisticated astro-compass, is seldom used except in long range bombers and spacecraft. It requires almost 1 ft^3 (28.3 dm^3) weighs about 12 lb (5.4 kg) and costs almost $20,000. It is a poor candidate for conventional airship navigation because unless special observation platforms are built in the topside of the airship, observations are restricted to celestial bodies having low astronautical elevation.

Since 1930, progress in the development of electronics components has made possible new families of navigation avionics. Of these, perhaps the most widely used is the VOR/DME/ILS which, packaged either separately or integrated together into a single unit, can provide bearings to VOR stations, ILS localizer and glide slope deviations, and marker beacon interception. A typical integrated system occupies only 260 in.^{3} (4261 cm^3) weighs 9 lb (4.1 kg) consumes 45 W of power, has an

accuracy of ±10° in bearing and ±3 μ in ILS deviation. The MTBF is 1000 hours and cost is about $3750. TACAN performs the same functions as VOR but also adds distance information. Unfortunately, TACAN occupies about 1.25 ft^3 (35.4 dm^3), weighs about 45 lb (20.4 kg) and has a MTBF of only 500 hours. In addition, bearing accuracy is only ±2.5°.

Since the end of WWII, radar has been available for air vehicle use, and in a non-military application is used for weather detection and ground mapping. Typical systems occupy 2.5 ft^3 (70.8 dm^3), weigh more than 50 lb (22.7 kg), consume about 500 watts in producing its 20,000 watt pulses, and cost in the neighborhood of $12,000.

Two of the newest navigation systems, still partly under development, are LORAN and OMEGA. Both are low frequency hyperbolic navigation systems with transmitting nets located to give as near as possible complete coverage of the surface of the earth. LORAN occupies about .25 ft^3 (7.1 dm^3) and weighs 18 lb (8.2 kg). It uses about 200 watts, has an MTBF of 500 hrs and costs about $25,000. OMEGA is much larger and heavier, occupying about 1.7 ft^3 (48.1 dm^3) and weighing about 85 lb (38.6 kg). It uses about 125 watts and has an MTBF of 1500 hours. No cost data on OMEGA is available. Typical accuracies for LORAN and OMEGA are 1.5 NM (2.8 km).

Perhaps the most sophisticated of modern navigation systems is the inertial system. Its typical 1.25 ft^3 (35.4 dm^3) volume and 80 lb (36.3 kg) weight are offset by its 1 NM/hr (1.9 km/hr) CEP accuracy. However, its low MTBF (930 hours) compared with its high typical cost ($125,000) often force selection of a more cost effective system, even though accuracy may be somewhat less.

3.2.3.5 Miscellaneous Equipment

Review of available literature on airships revealed the existence of several other items which in 1930 probably were mechanical but which today probably would be electronic. Because of lack of data covering the 1930 equipment and because much of the equipment is no longer used such items are considered beyond the scope of this trade study. However, they are mentioned because of their potential applicability to future airships. Three of these--the gas pressure indicator, the gas leak detector, and the gas purity indicator--were carried solely for the monitoring and analysis of conditions of the lifting gas medium. In flight above 10,000 feet oxygen was normally carried, and this required oxygen regulating equipment. Onboard recording of altitude and pressure were accomplished by the barograph and the altigraph. Pressure and temperature are vital to the determination of the density of the environment and the lifting gas. These data were used in conjunction with

a lift computer, which was used to determine the lifting capability of the vehicle for a known set of conditions. Finally, in those vehicles where the airship frames employed wires as crossmembers to provide extra frame rigidity, a tension indicator was employed to check the tension of these members.

3.2.4 Control Systems

3.2.4.1 Flight Controls

3.2.4.1.1 1930 State-of-the-Art

The 1930's airship was controlled from the bridge in the forward gondola. Directional control was commanded by a helm which was facing forward, Figure 3-17, and the altitude by another helm located laterally, Figure 3-15. In addition, in the large rigid airships there was an emergency control station in the lower fin with controls for both rudders and elevators.[9] See Figure 3-28.

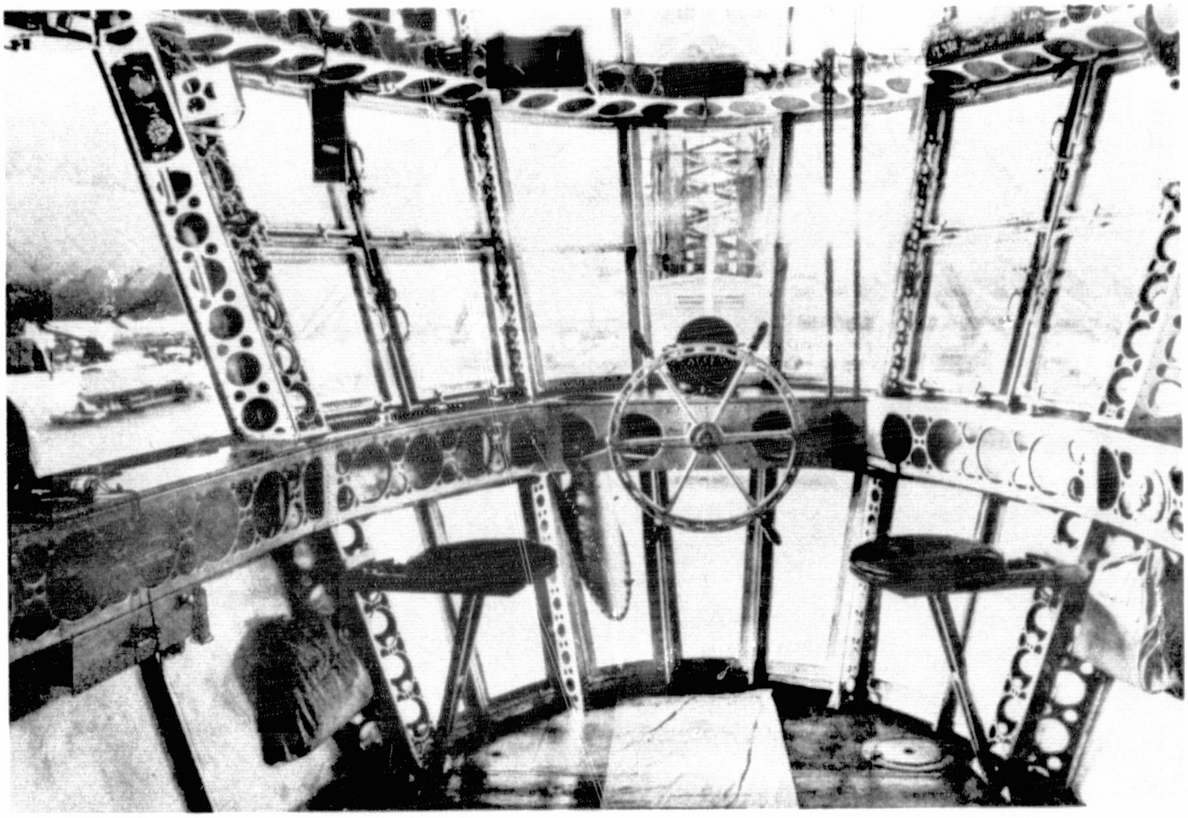


Figure 3–17. U.S.S. Macon, Directional Control Station

The control system further comprised systems for release of trail ropes, water ballast, gas valving, etc., as well as telegraphs for mooring instructions and power demand from the engines. (The engine control system has been discussed in Paragraph 3.2.2, Propulsion.) Typical airship control system in the 1930's is illustrated in Figure 3-18.

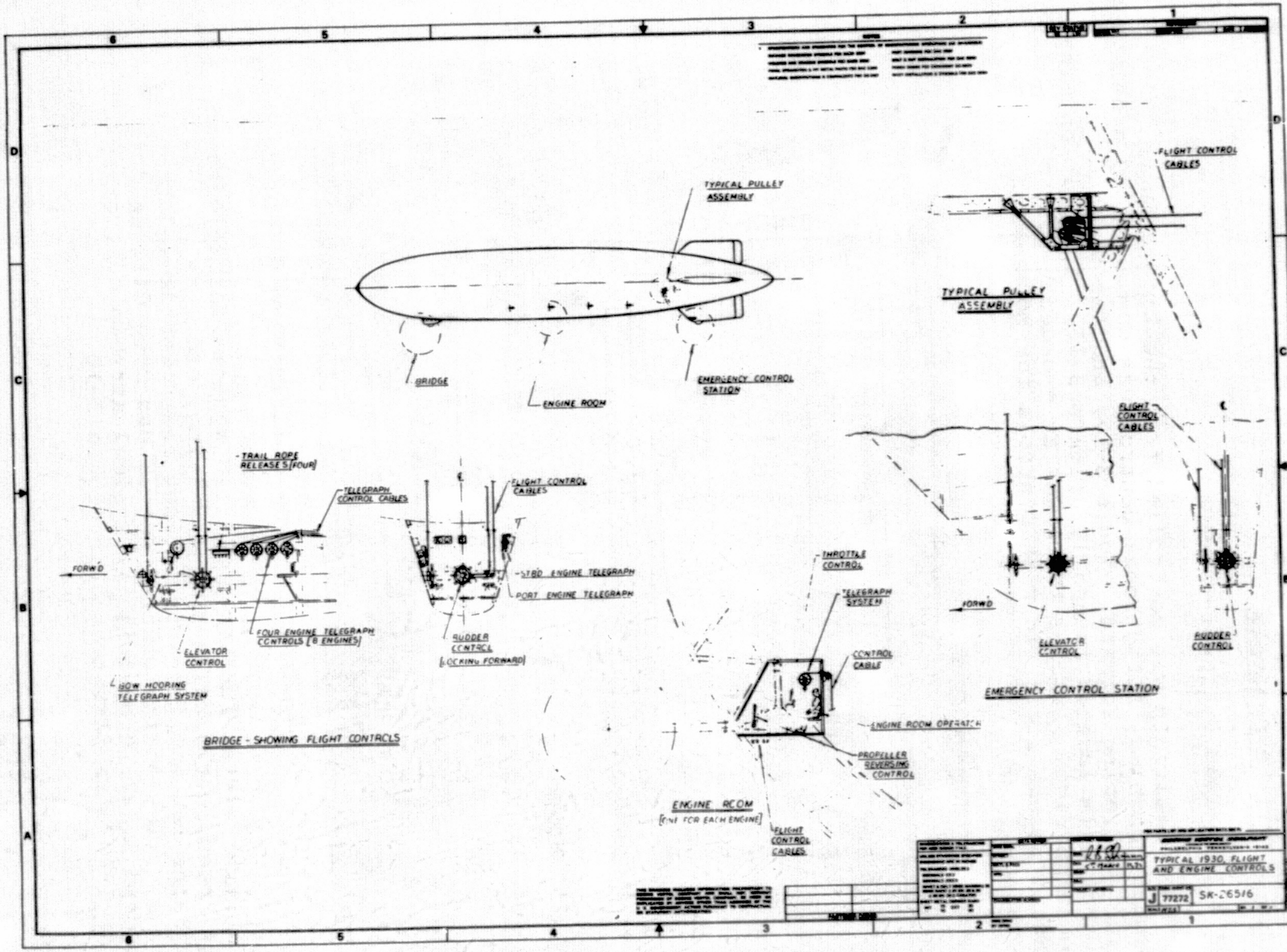


Figure 3–18. Typical 1930 Flight and Engine Controls

ORIGINAL PAGE IS
OF POOR QUALITY

All control demands were transmitted by steel cables. This required an elaborate system with tension pulleys which compensated for slack or increased tension due to different elongation of the aluminum structure and the steel cables in the rigid airship when the temperature changed. The non-rigid airship required the same system to keep proper tension in the control cables. A control cable pulley assembly in the Akron can be seen in the upper right hand corner of Figure 3-28.

Since 1930, the aerospace technology applicable to the control and stabilization of an airship has gone from its infancy to maturity in the early sixties, but has produced very few potential contributions to airship performance in the last ten to fifteen years. Although largely evolutionary, the development did take a few leaps forward with the invention of the electrohydraulic servovalve and the transistor and the advances in servo control theory. Recent improvements have been mainly in maintainability and reliability which have made more complex devices practical and permitted the introduction of fly-by-wire and other techniques which could have been used fifteen or more years ago but would not have been cost effective at that time. Besides improvements in hardware, the use of simulation - the electronic computer, the cockpit simulator and the wind tunnel - has reduced the development cost of aircraft by reducing the time required for flight test optimization.

3.2.4.1.2 1975 State-of-the-Art

The detail configurations of a 1975 state-of-the-art control system of an airship is highly dependent upon the configuration of the LTA vehicle itself. However, it seems quite reasonable that a typical system will consist of the following elements:

a. A control station with airplane type controls for conventional or STOL aircraft and with helicopter controls for the VTOL versions. Some additional cockpit controls unique to airships may be required. Since it is assumed that the control system would be fly-by-wire, the cockpit controls would be operating only transducers to produce appropriate electrical signals. They could therefore be optimized for ease of control and smoothness of operation even though the end result would be motion of some large control surface.

b. A package of sensors and electronics to produce the appropriate control surface actuator motions in response to pilot or autopilot inputs. The sensors would include but not be limited to the pilots control pickoffs, vertical and directional gyros, airspeed and altitude sensors and actuator position transducers. Some of these sensors would be shared with requirements for flight instrument Others would be dedicated to the flight control system. The electronics system which is the most difficult to predict at this time would include the redundant circuitry to provide a safe fly-by-wire system and elements of automatic stabilization. Automatic navigation and hover hold circuitry if applicable would be integrated with the flight control electronics even though it might not generally be considered part of the flight control system.

c. Assuming a fly-by-wire control system, a set of actuators either electric, electrohydraulic or electropneumatic.

d. The control surfaces. For conventional and STOL airships the surfaces will also be conventional, i.e. ailerons, elevator and rudders or some surfaces have two or more of these functions or thrustors. VTOL may have similar surfaces or thrustors for forward flight but will require rotors of some sort to supply control and possibly lift at zero airspeed.

A 1975 state-of-the-art control system with equal functions, will save up to 20% in weight when compared with the 1930's system. A modern system can, moreover, improve the control of the airship considerably. This will, of course, entail an increase in cost.

3.2.4.1.2.1 Control

Although the control surface configuration for conventional airships will probably not change appreciably from the practice of 1930, until the efficiency of thrustors has been evaluated and proven superior, the configuration for VTOL airships must be the subject of considerable study in order to arrive at an optimum configuration. To be determined are:

- The number of rotors thrustors
- Their location
- Their diameter

- Their solidity
- Shaft tilt, fixed or variable and a function of what
- RPM fixed or variable and a function of what
- Collective pitch
- Cyclic pitch

For the VTOL, propulsion must be considered in conjunction with lift and control. As in a helicopter, the lifting rotor can supply both thrust for propulsion and a rotating moment for control. The lifting rotor can supply thrust by tilting the shaft, by adding cyclic pitch or by changing aircraft attitude or any combination of these three. The mission will have a large effect on the choice. For example, an airship which is used primarily for transporting heavy cargo short distances might hover in a level attitude and use differential collective pitch to tilt the whole airship and thereby tilt the thrust vector and provide propulsion. This aircraft could operate without cyclic pitch or shaft tilt. If the cruise requirement was predominant, a similar aircraft but with shaft tilt fixed at the optimum angle to allow the airship to be level for cruise would then hover nose up. For a general utility airship where level attitude may be required during cruise and hover, some shaft tilt and cyclic tilt may be required.

Another special mission requirement might be long range cruise at high efficiency but with a short term hover capability. For this requirement the airship could have an aerodynamic planform for auxiliary lift in cruise, and a rotor for auxiliary lift in hover and which could be tilted forward for propulsion in cruise.

3.2.4.1.2.2 Actuators

Having chosen the control surface configuration, the actuation trade off becomes relatively easy. In most aircraft, hydraulic actuation is the obvious choice from both a weight and response standpoint. From a safety standpoint, it is also less prone to jam than competing electrical or pneumatic actuators which would require some sort of gear reduction. For an airship which may have redundant control surfaces, for which a jam is not so critical, electrical or pneumatic actuators may be considered. The reduced response which is characteristic may be tolerated on an airship. Some of the advantages of these less traditional control means are obvious. Power transmission and generation are easier and lighter. For the electrical case the power can be generated by increasing the size of the generators which will be required independently of the control requirement. The transmission will be accomplished by increasing the size and perhaps the number of wires which will be required anyway for either hydraulic or pneumatic actuation.

Pneumatic power generation could be bleed air from a turbine engine and low pressure lines which are not critical with respect to small leaks for power transmission. For a VTOL with an engine at each rotor, the transmission problem disappears. This would be true for the hydraulic case also if a pump were attached to each engine if it were not for the universal problem of long term maintenance of fluid in the system.

The power required to move the control surface will surely have a large effect on the choice of actuator. For low power requirements as on a small airship or one with servo tabs for aerodynamic boost, a good choice might be electrical actuation. For a large power demand, the electrical case with the additional generator weight and the large motor and gear train weight might be too heavy to compete with hydraulics. Pneumatics might compete but are not presently sufficiently developed to make the answer obvious.

3.2.4.1.2.3 Fly-by-Wire

The discussion thus far assumes fly-by-wire controls. This seems to be the preferred system, mainly due to the large sizes of an airship but has to be confirmed by a trade-off analysis for each specific airship configuration. In general, some of the compelling factors of a fly-by-wire system are as follows:

a. The long control runs which would be required for mechanical controls originated from a central control station would make such a system unwieldy and inaccurate. The probable friction, compliance and lost motions in the various runs would tend to make such a system unacceptable by contemporary standards.

b. Because of the low response of an airship, failure detection would not be as critical and contrary to a helicopter fly-by-wire system the concept of fail safe controls which are not necessarily fail functional might be viable.

c. For a VTOL airship with engines at each rotor and no synchronization shafting, the total rotor power, electrical power and actuator power required for fly-by-wire of that rotor could come from the one engine and require no transmission through the airship except for electrical signalling.

d. To add autopilot functions to an airship, some type of actuator must be used even if the control system is otherwise purely mechanical. Since such an

actuator must have the response and forces necessary to move the control surface, its use can easily be extended to provided fly-by-wire.

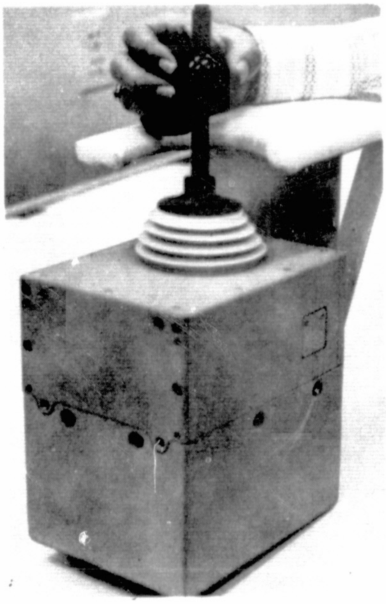


Figure 3–19. 1975 Side-Arm Control Stick

e. Comfortable, side-arm control stick. Figures 3-19 and 3-20 show a typical "finger-tip" control and its installation in Boeing Vertol research helicopter Model 347.

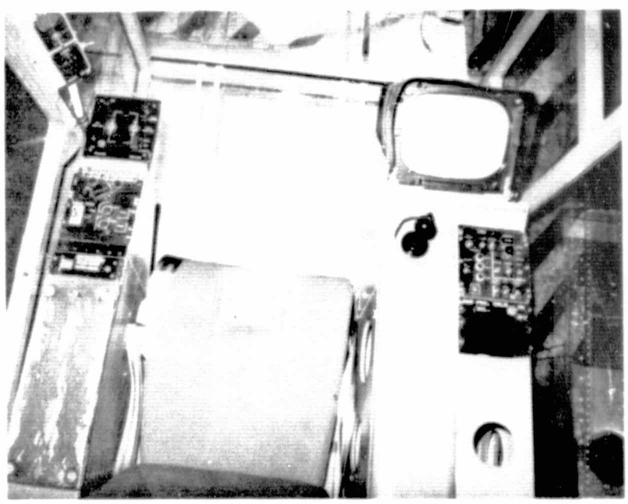


Figure 3–20. Advanced Control Station in Model 347 Research Helicopter

3.2.4.1.2.4 Autopilot

Routine control of the modern airship would be the function of an autopilot. 1975's technology permits the design of an autopilot which can fully control the airship within its design limitations. The block diagram in Figure 3-21 illustrates how several inputs are integrated in a computer which then feeds the appropriate signals to the various controls to adjust the flight condition to give pre-programmed course or to prevent the structure from becoming overstressed. Load sensors should be installed at strategic points.

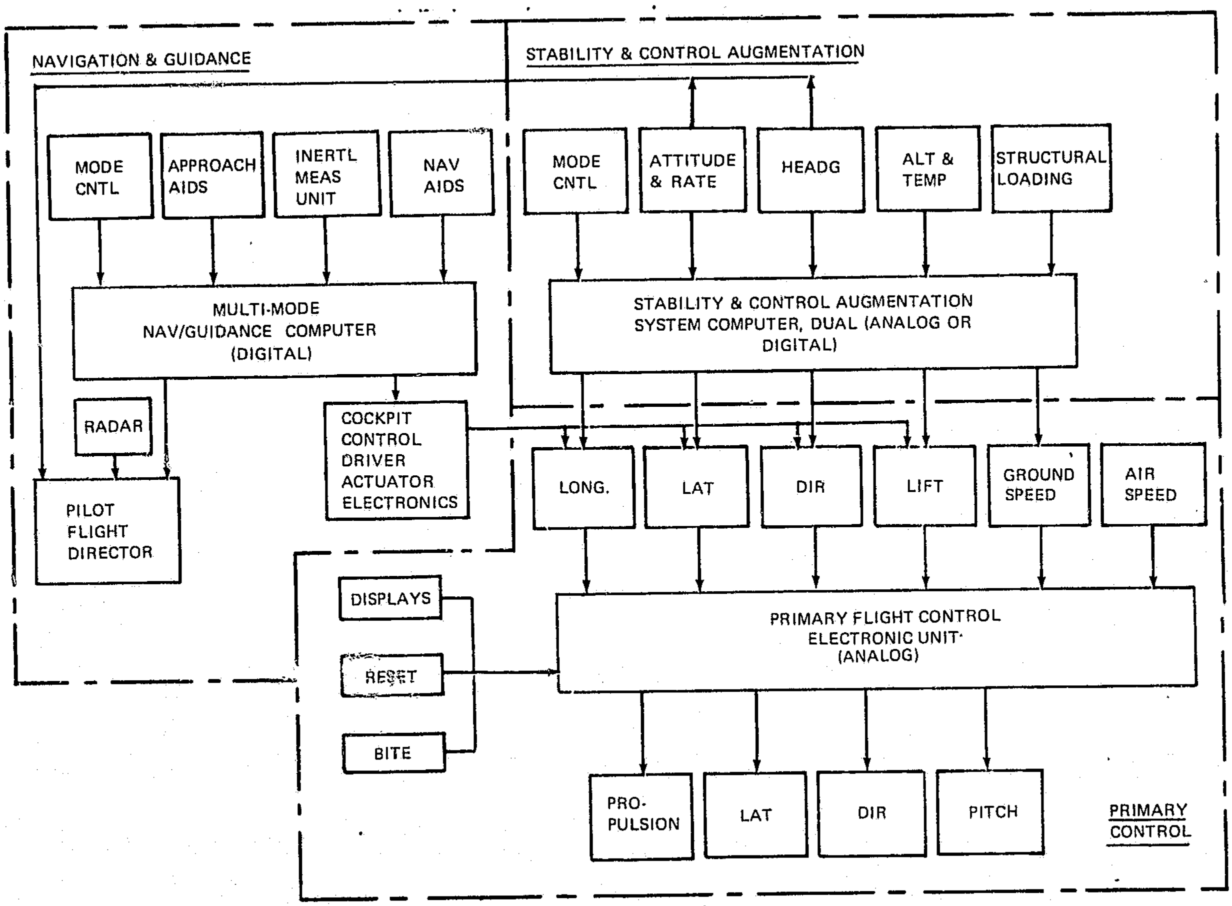


Figure 3–21. Autopilot Block Diagram

3.2.4.2 Superheat

Superheat (difference between lifting gas temperature and surrounding air temperature), positive or negative causes variations in the static lift of an airship. This calls for compensation by change in dynamic lift, release of ballast, or a combination of both.

Other means of control, such as compression of the gas or artificial heating/cooling of the same has been suggested.

Figure 3-22 and 3-23 are two actual records of superheat experienced by Los Angeles when she was moved out of the hangar at Lakehurst.[12]

Analyzing the plot in Figure 3-22, the superheat increased 12°F (6.7°C) in 30 minutes when the Los Angeles was moving out of the hangar into the field. From take-off and to 1,800 ft. (550 m) a negative superheat of 20°F (11.1°C) was developed in 22 minutes. This latter change was due to the cooling effect of the wind; the ambient air temperature actually increased during the take-off maneuver.

When the airship was walked out of the hangar, the static lift, or displacement, increased by 2.5%. During take-off the static lift decreased by 4%, which had to be compensated for by dynamic lift as the Los Angeles picked up speed.

The following will examine the fasibility of the two mentioned methods to compensate for the change in superheat without using dynamic lift or release of ballast compression and artificial heating, respectively.

The pressure can be varied by changing the pressure of the air in the ballonets. In the case of a rigid airship, each gas cell has to be fitted with a ballonet.

Referring to Figure 3-22, the gas pressure during walk out would have to be increased by .4 lb/in^2 (281 kg/m^2) in 30 minutes and during take-off decreased by .6 lb/in^2 (422 kg/m^2) in 22 minutes. The power required to transport required air mass at these pressures is very reasonable - less than 10 H.P. However, the weight of the envelope or gas cells will increase due to the increased load, in such a degree that 75-85% of the payload capacity must be sacrified. Thus, pressure compensation is not feasible.

Using a concept with artificial heating/cooling and examining the negative superheat of 20°F (11.1°C) in 22 minutes during take-off (see Figure 3-22), it will be found that an addition of 640,000 BTU (161,255 kcal) in 22 minutes will be required

to keep the static lift constant. This heat requirement needs an energy source to supply 1.75 x 10^6 BTU/hr (441 x 10^3 kcal/hr). The exhaust gases of a modern 217 HP turboprop engine contains that amount of heat.

A modern airship will have considerably more heat than required for artificial heat in the exhaust gases. Thus, artificial heating and cooling as well, inasmuch as the same plentiful source of energy can be used for refrigeration, is feasible.

A more detailed study of such a heating/cooling system including weight penalties and development requirements will be performed in the Phase II part of this study.

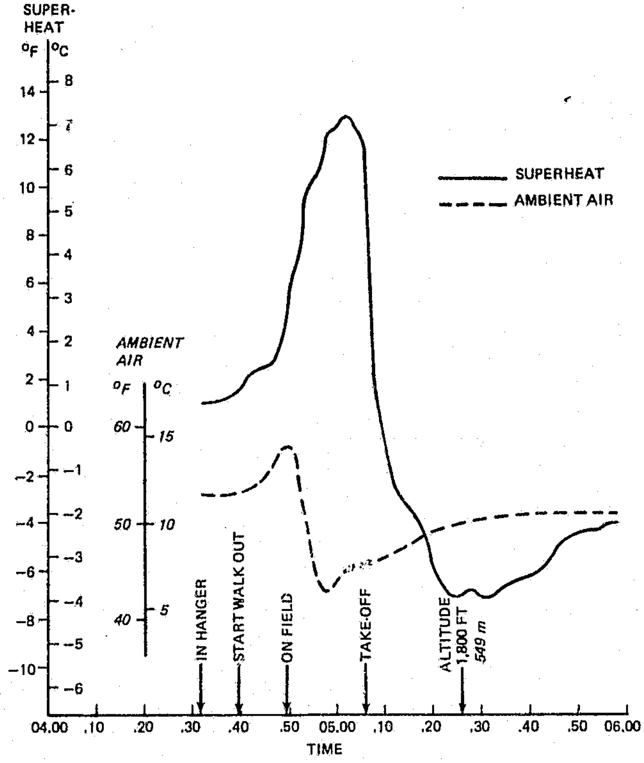


Figure 3–22. U.S.S. Los Angeles, Superheat on 2 May 1926

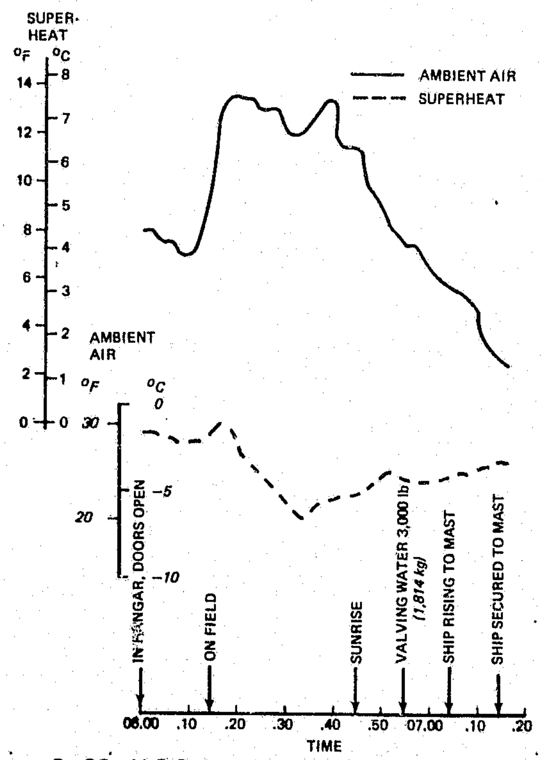


Figure 3–23. U.S.S. Los Angeles, Superheat on 12 November 1926

3.2.5 Materials and Structures State of the Art

3.2.5.1 Airship Materials

An overview of the state of the art advances in materials from 1930 to the 1975 time period may be gained from a cursory look at the material alternatives presented in Figure 3-24. The 1975 materials for the primary applications (framing, coverings, cells/envelopes, and wiring) show large gains in specific strengths as well as improvements in fatigue strengths, permeability, corrosion resistance, and aging. Table 3-X illustrates

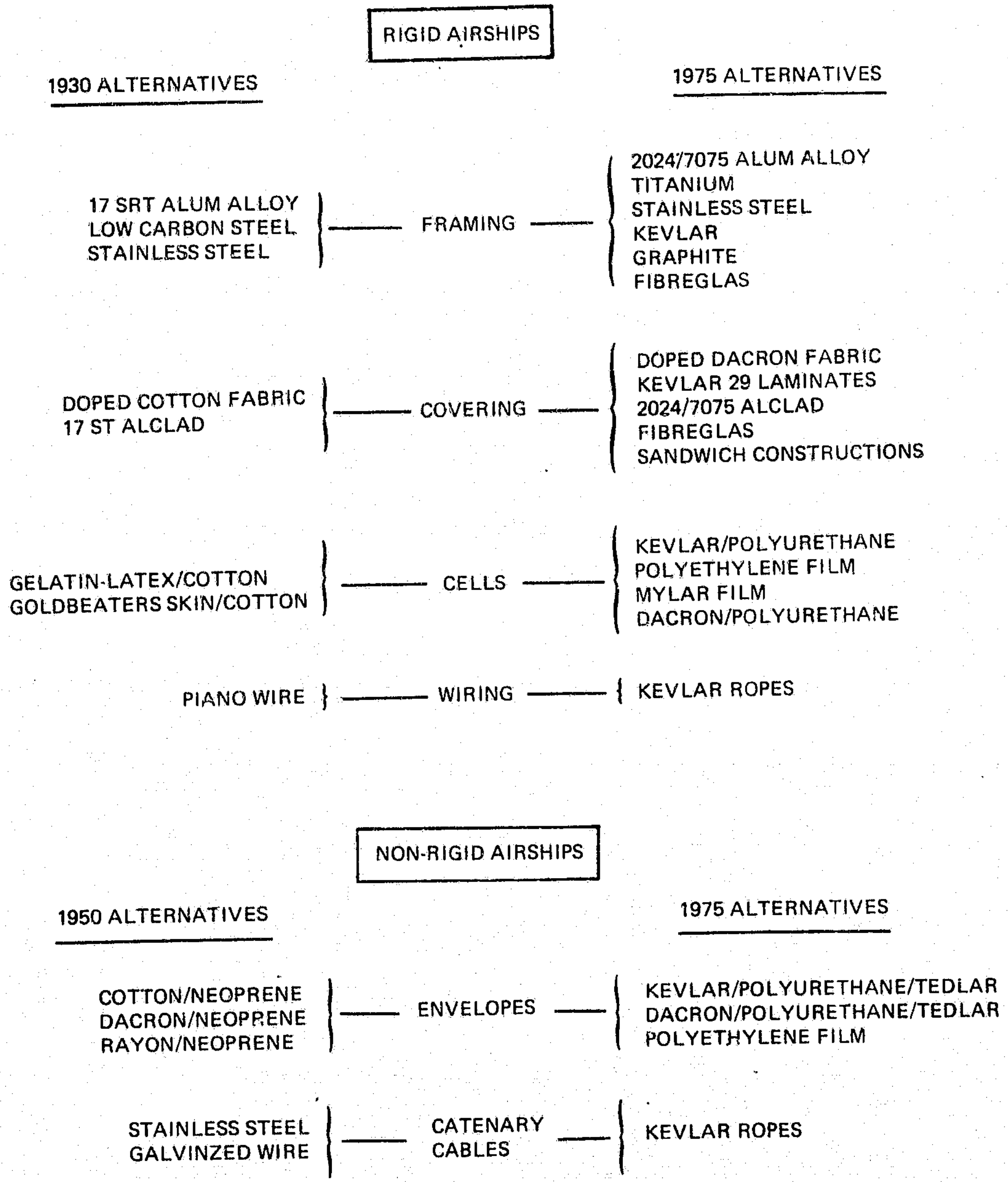


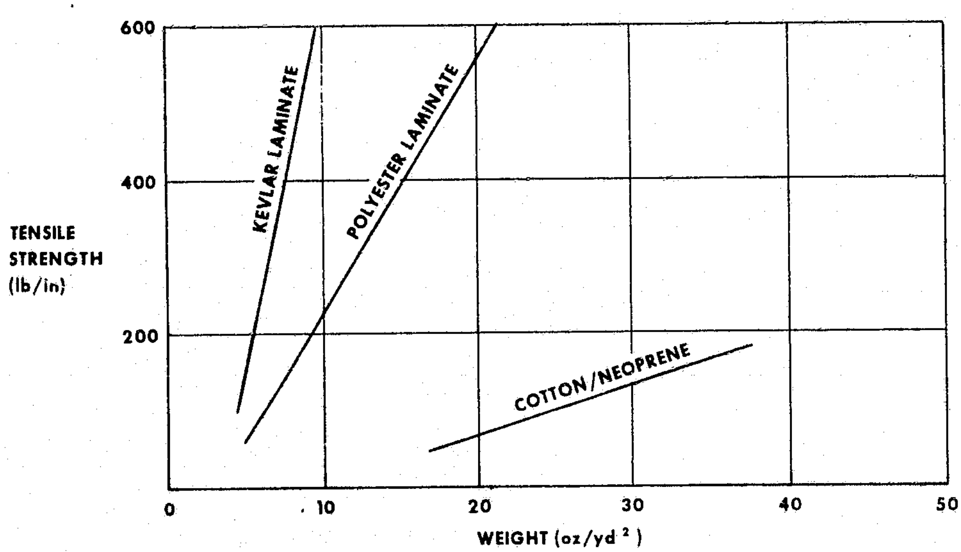
Figure 3–24. Materials Alternatives

Table 3–X. Materials Comparison [11, 61, 62]

1930			1975	
MATERIAL	SPECIFIC TENSILE STRENGTH UTS/DENSITY in. X 10^{-3}		MATERIAL	SPECIFIC TENSILE STRENGTH UTS/DENSITY in. X 10^{-3}
17 ST	580	ALUMINUM ALLOY SHEET	2024-T3 7075-T6	660 752
CARBON	353	STEEL	300 MARAGING	1040
–––	–––	TITANIUM	Ti 6A1-4V	1000
–––	–––	COMPOSITES	1002 S-GLASS KEVLAR 49	2650 2230

Conversion factor: 1 in = 25.4 mm

the improvements in aluminum alloys along with other candidate framing materials. The tremendous improvements available in covering, envelopes, and cell materials can be seen in Figure 3-25. Further detailed discussion can be found in Appendix B. In the area of wiring and netting, as well as catenary cables, KEVLAR rope constructions show 4 or 5 to 1 improvements in weight over the same strength wire rope.[11]



Conversion factors: 1 oz/yd^2 = 33.91 gm/m^2
1 lb/in = 1.75 n/cm

Figure 3–25. Envelope/Cell Strength/Weight Comparisons

3.2.5.2 Airship Structures

The framing construction of nearly all 1930's rigid airships had not changed in its fundamentals since the earliese Zeppelin airships. This construction is the following (Figure 3-26 and 3-27): A series of polygonal transverse rings is joined at the corners by longitudinal girders; the rectangular panels formed by the ring sides and longitudinal girders are stiffened by wire bracings, which are applied in a single or double panel arrangement. Besides this "external panel stiffening" another "inner net bracing" is usually present, which attaches to the inner faces of the longitudinals and serves for the transferring of the gas forces exerted by the cells. Thus the constituted enveloping surface forms a stable space framework, which structurally is known as a basket frame. By stiffening of all or of only some transverse rings of this basket frame, a structure of high bending and torsional stiffness is obtained.[60]

While this structure is very efficient and light-weight, examination of the typical girder and joint constructions shown in Figure 3-28 indicates the high degree of complexity and the work-intensive nature of these airships. Although little modern detailed airship structural design has been recorded, it appears that the 1975 structural design approach should take advantage of the high specific strengths and other advantageous characteristics available from the composite materials (such as KEVLAR and S-Glass) in the most simple structural concept possible. Figures 3-29 and 3-30 illustrate schematically two approaches to a 1975 conventional rigid airship. Further discussion and weight analyses of these concepts appear in 5.2.3.

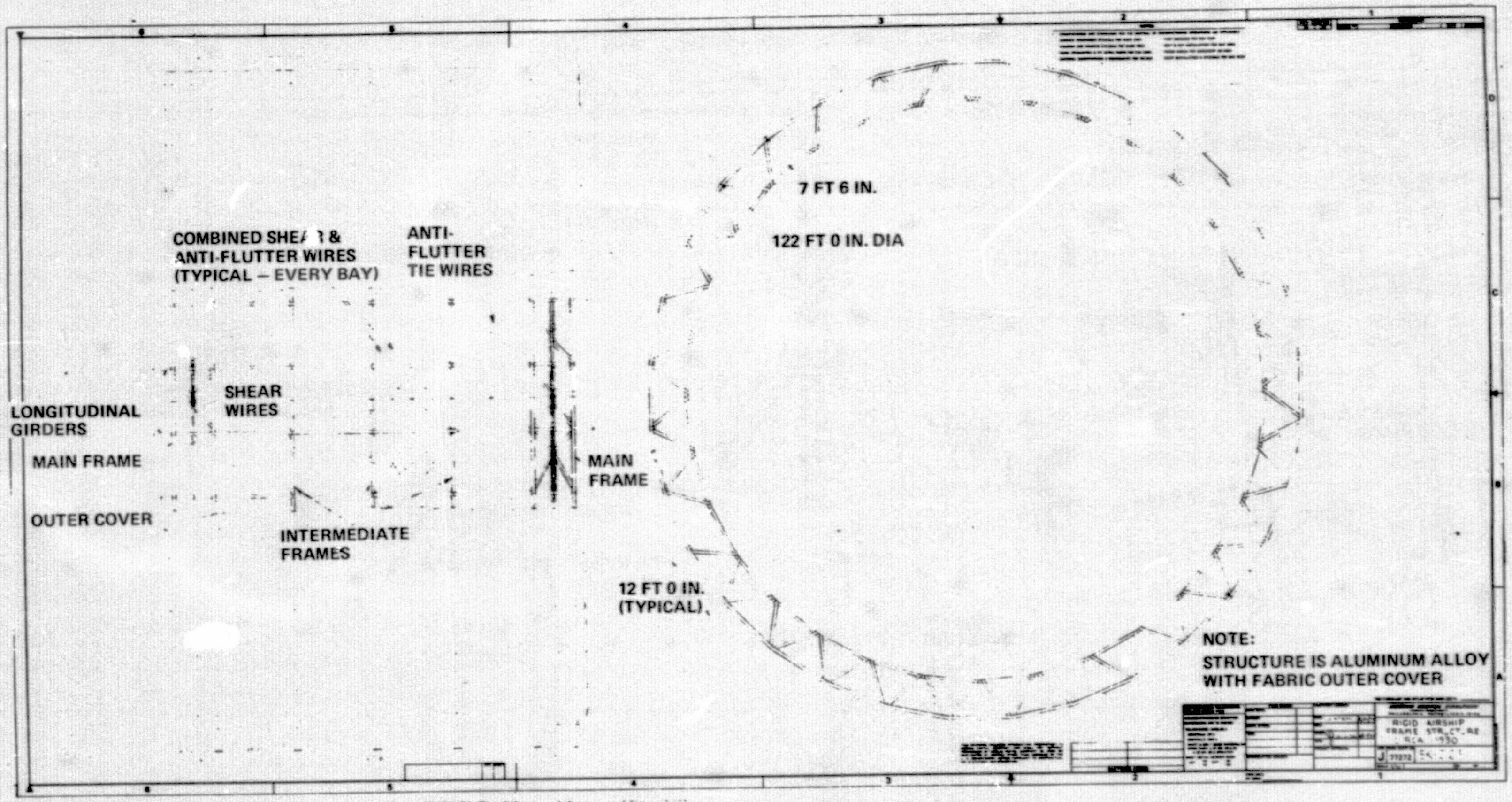


Figure 3–26. Rigid Airship Frame Structure, Circa 1930, General Arrangement

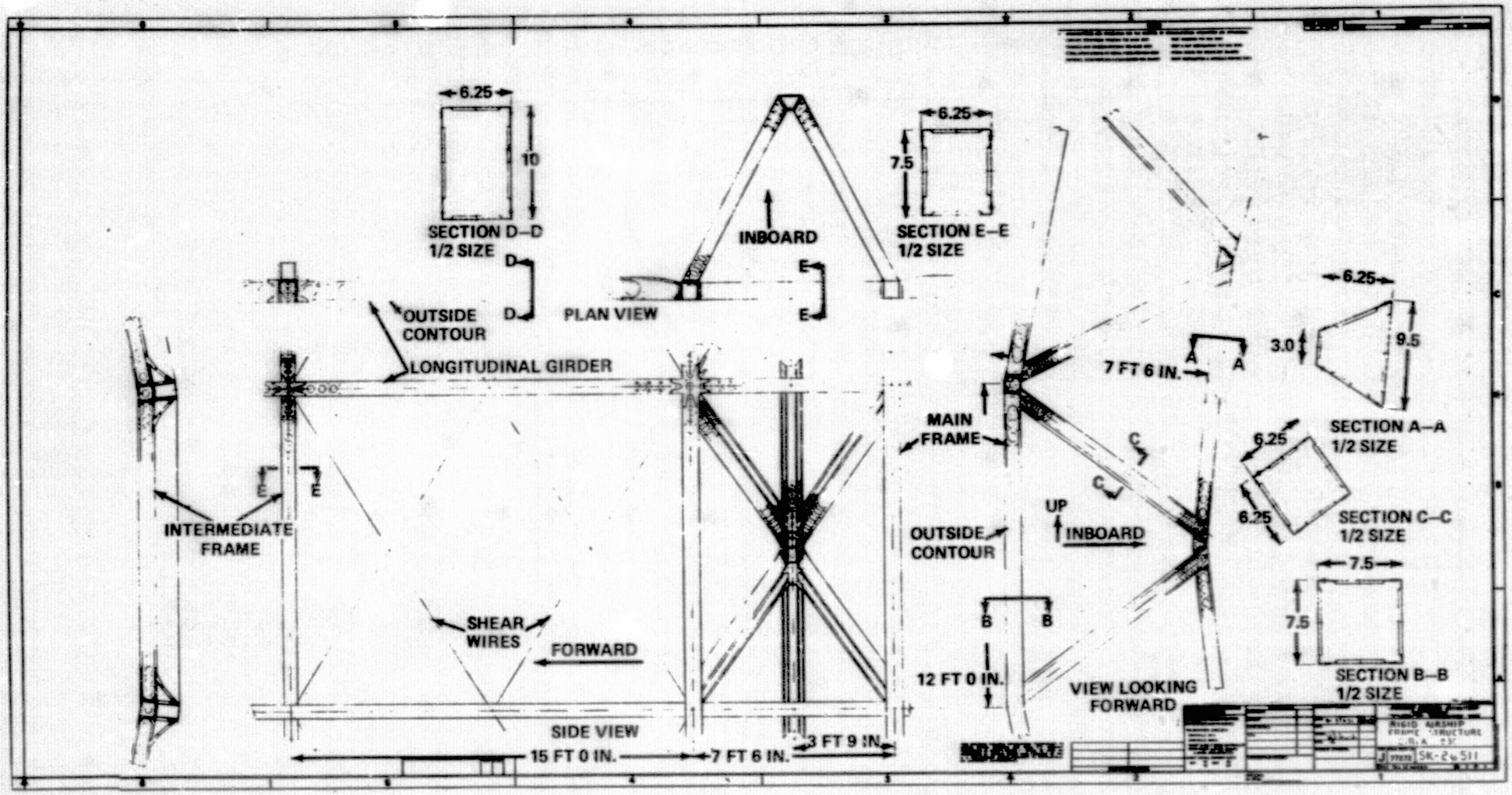


Figure 3–27. Rigid Airship Frame Sturcture, Circa 1930, Details

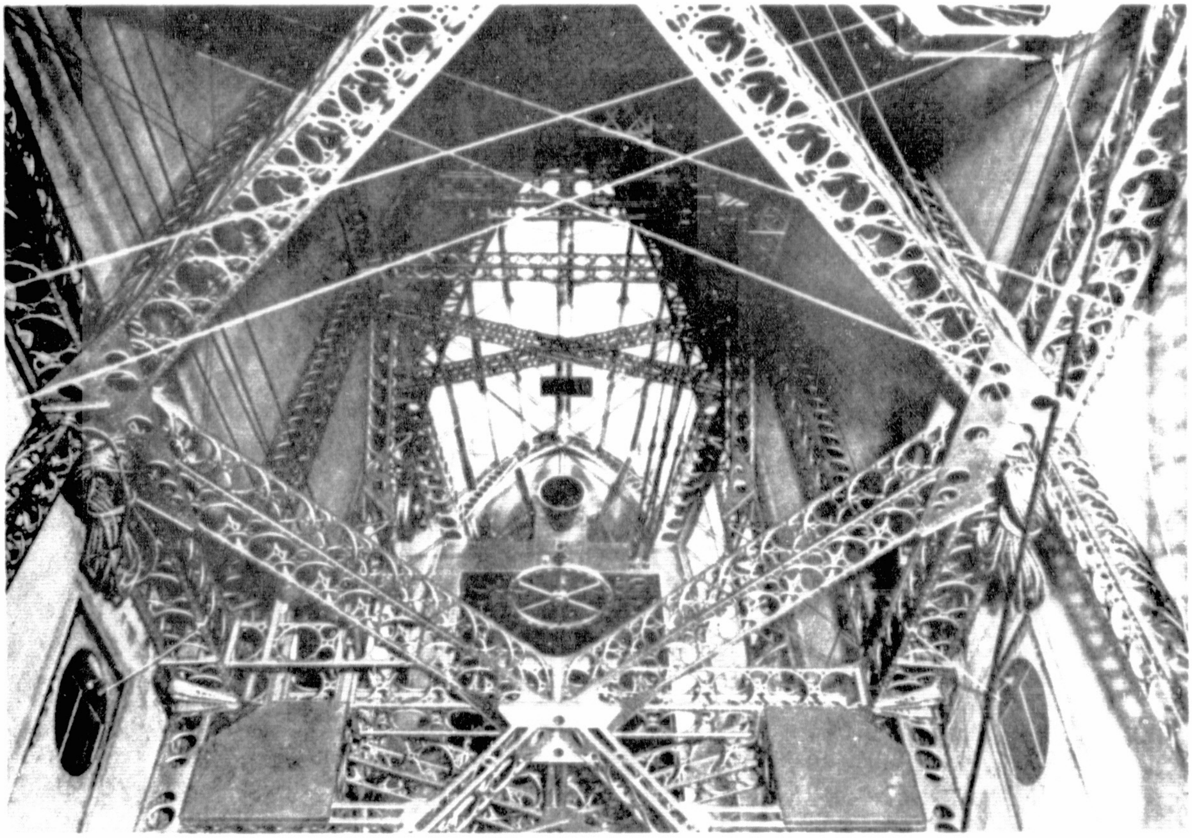


Figure 3–28. U.S.S. Macon Structure in Lower Fin

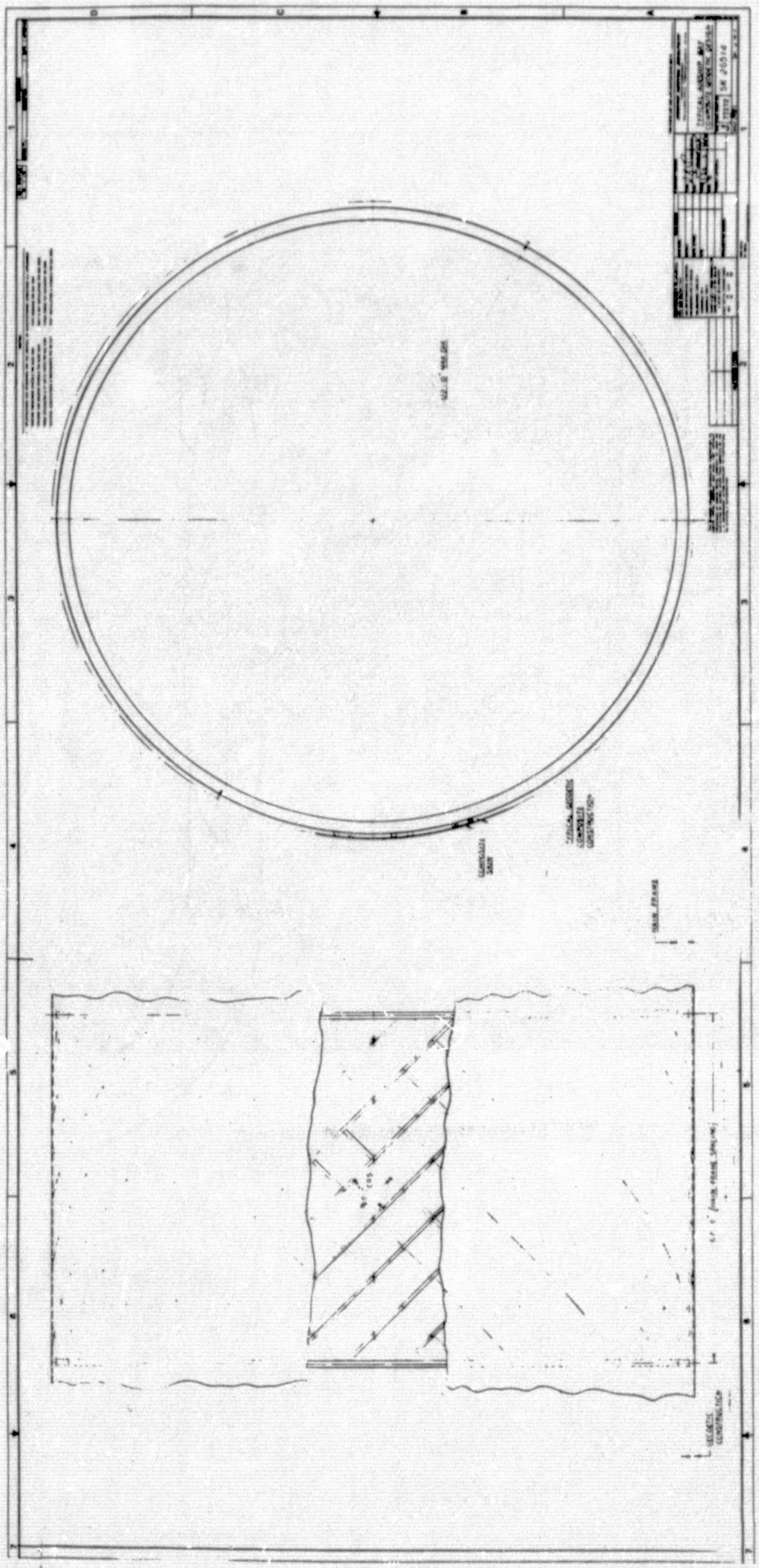


Figure 3–29. Typical Airship Bay, Composite Geodetic Design

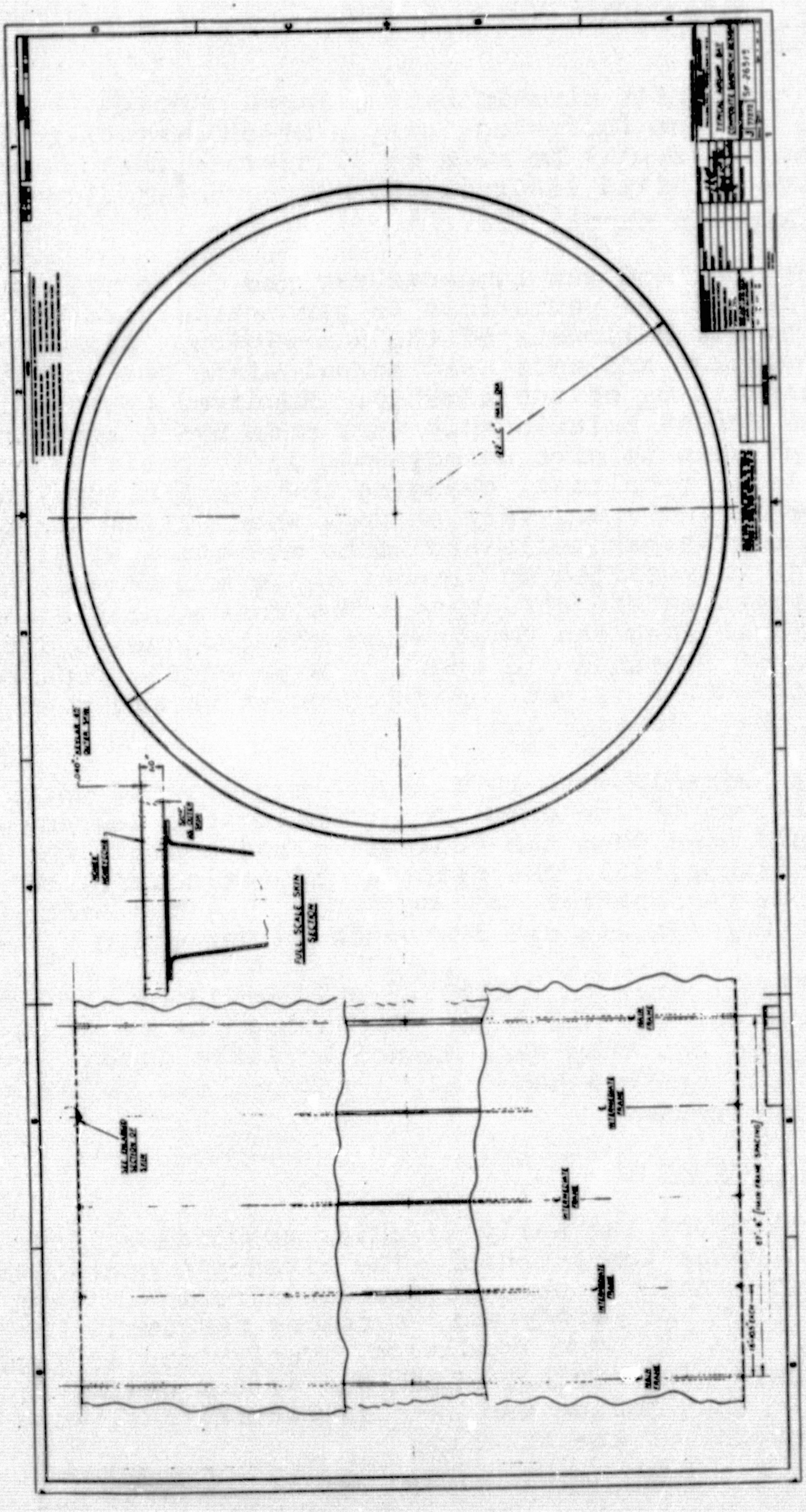


Figure 3–30. Typical Airship Bay. Composite Sandwich Design

3.2.6 Operating Procedures

3.2.6.1 In Flight

Operation of the 1930's airship kept a large onboard crew constantly busy. In the following, only a brief mentioning of several of the tasks will be made to illustrate the operation. For authorative detailed instruction, reference should be made to the Rigid Airship Manual 1927.[12]

When in flight, air and gas temperatures had to be monitored all the time as well as variations in barometric pressure and pressure in the air ballonets of the non-rigids. All parameters were important and were used to calculate the prevailing static lift capability of the airship. Required changes in the lift/gross weight relationship were made by introducing pitch of the airship to give aerodynamic lift (positive or negative), releasing ballast, changing the air pressure in the ballonets (non-rigids), or, very seldom, when helium was used, valving of gas. The gas cells had to be monitored at altitude changes so that they filled up without folds and creases and did not get caught in the structure. The control cable tension had to be adjusted when the temperature changed due to different elongation of aluminum and steel.[12] Even engine repairs were sometimes made in flight. Navigation which was dead reckoning, occupied several men.

Operation of an airship with 1975 technology applied would unload the workload of the crew to a considerable degree. A computer would take over the monitoring and control the airship via an autopilot. The pilot would, of course, be able to override the control at any time. (The state-of-the-art of control systems are discussed in Paragraph 3.2.4)

The required flight crew in a 1975 airship would be a fraction of the large crew of the old days. An analogy is seagoing ships; 25-30 years ago they were manned by large crews. Today, even the giant oil tankers have only a few men due to automated monitoring systems.

3.2.6.2 On the Ground

Landing and docking of the early airships required a large ground crew to assist the airship. The airship's controllability was considerably reduced at the low airships. Very little control from the aerodynamic surfaces remained, if any, depending upon the wind condition. Variations in engine power, ballast and gas valving, which was seldom used because of the high cost when helium was used as lifting gas, were the means of control of the airship.

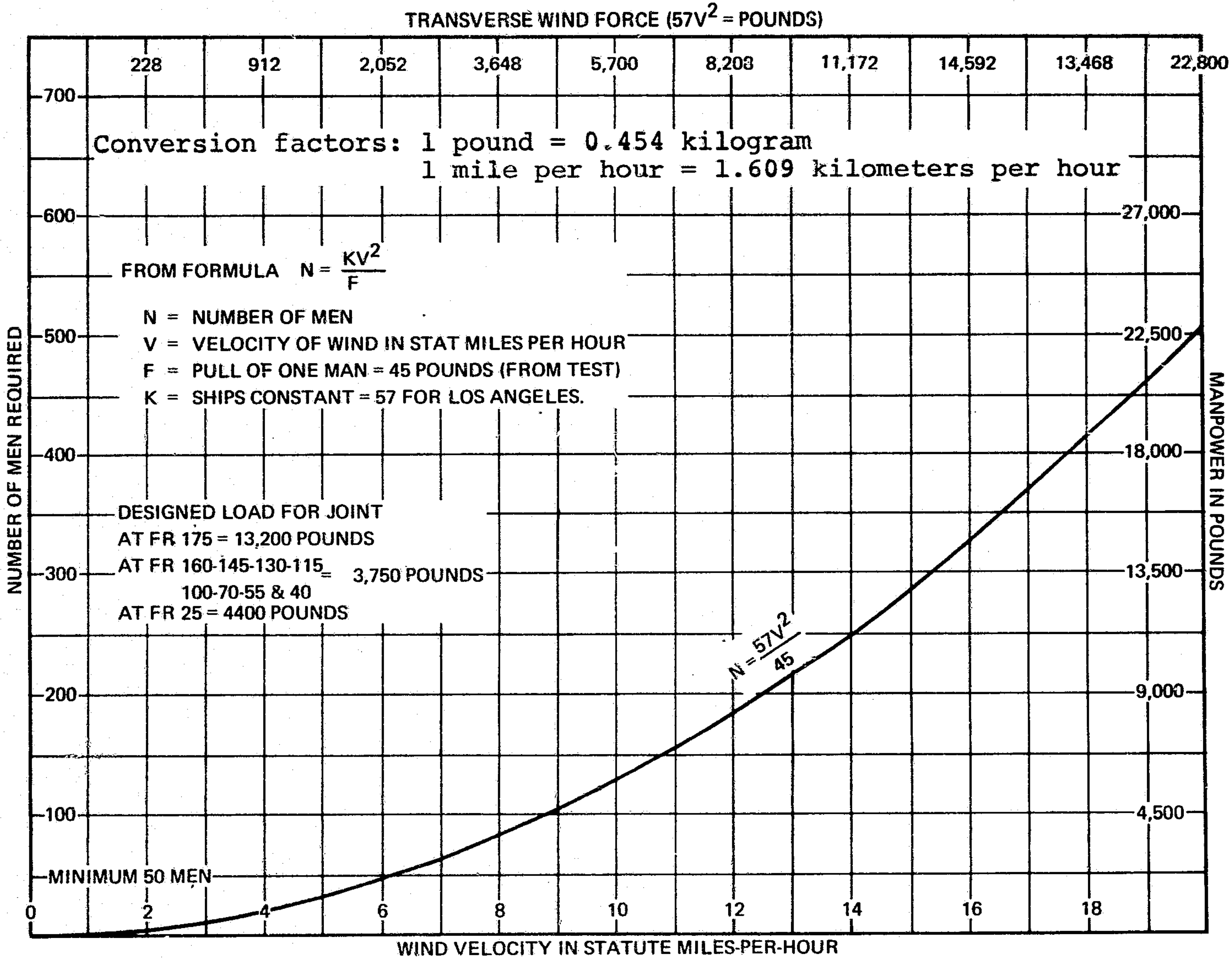


Figure 3–31. Required Landing Crew Per Side for U.S.S. Los Angeles

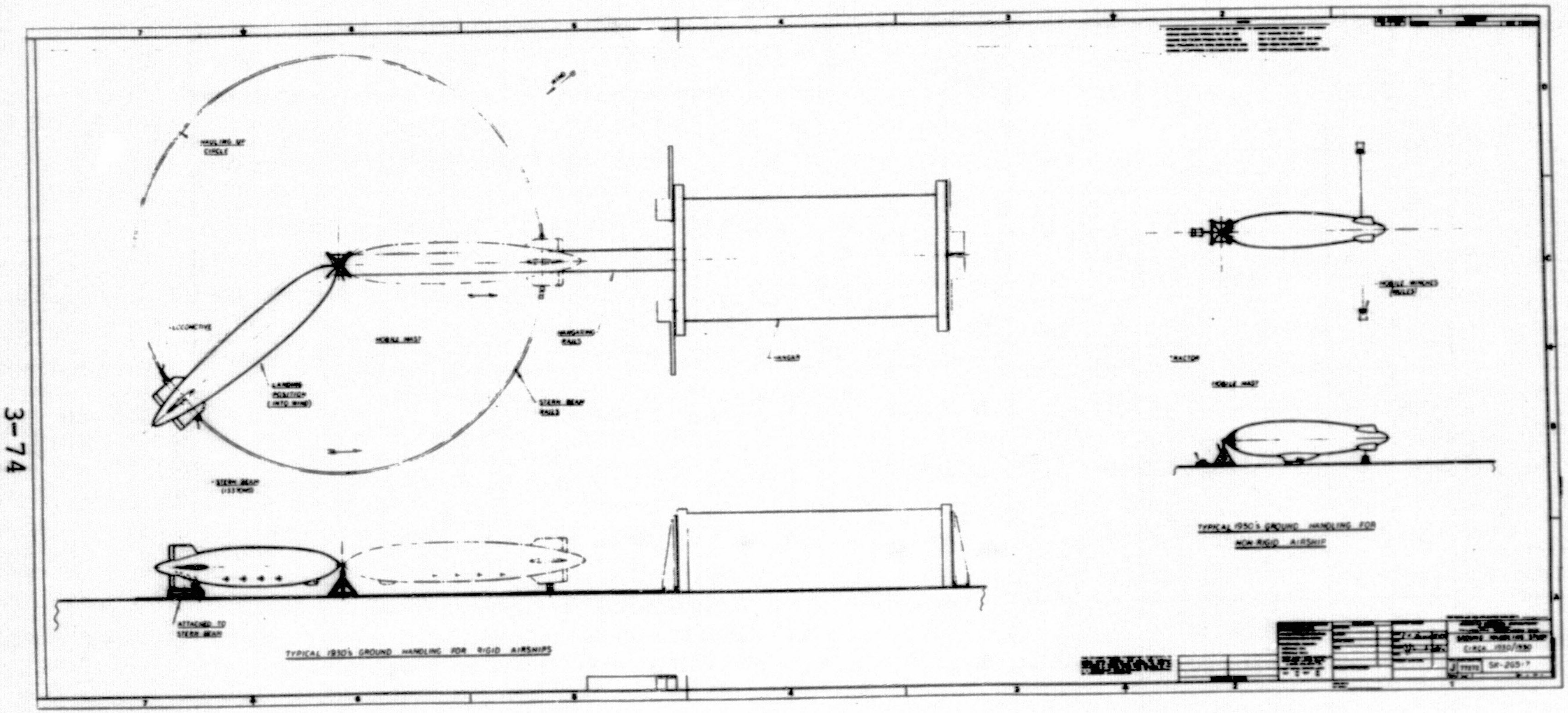


Figure 3–32. Typical Ground Handling Methods in 1930-1950

Safe landing required, therefore, assistance from the ground. Figure 3-31[12] presents the number of men per side for landing the Los Angeles at different wind velocities. The minimum number required, at no wind condition, was 100 men in total. A wind of 15 kt (7.7 m/s) required a total of 560 men if wind is broadside.

Much improved landing techniques including mechanization were developed over several years. The U.S. Navy, especially, expended large efforts to simplify the landing, docking and take-off procedures for airships. Thus, in the 1960's, airships as large as $1.5 \times 10^6 ft^3$ ($42.48 \times 10^3 m^3$) (the ZPG-3W) were docked to a mobile railroad mast with a ground crew of only 12-18 men with a pair of "mules", i.e., mobile winches.[11] Figure 3-32 illustrates a typical ground handling system in the 1950's and 1960's. Figure 3-33 shows the Akron moored to the stub-mast at Lakehurst

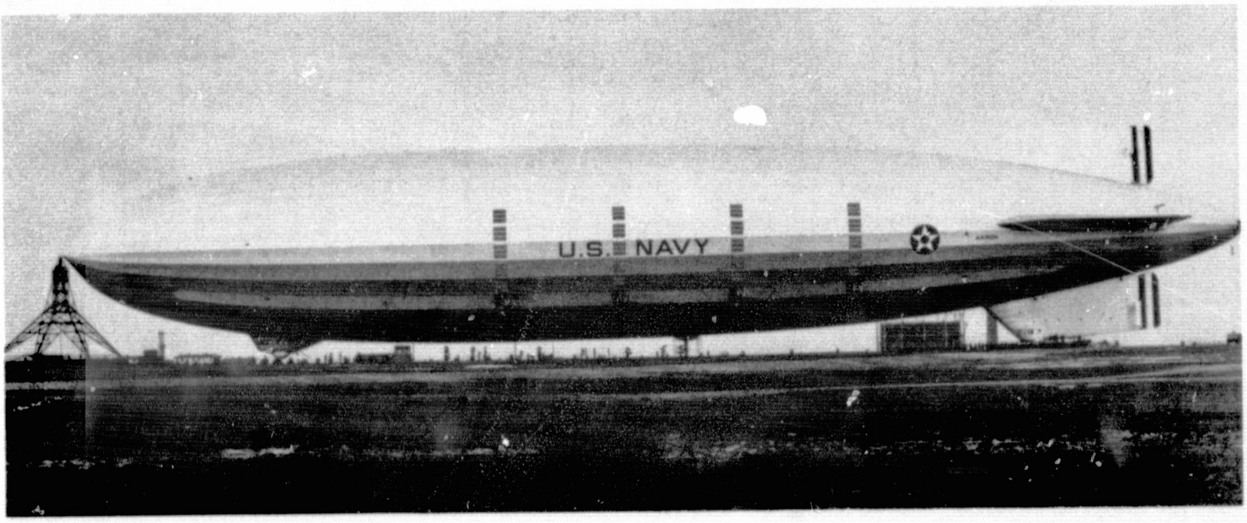


Figure 3–33. U.S.S. Akron at Lakehurst Stub – Mast

The concepts for "modern" ground handling methods will be analyzed in Phase II of the feasibility study program. However, a preliminary examination has been done in this Phase I part to offer a comparison of the 1930's state-of-the-art and the possibilities of the 1975's technology.

One concept to improve the docking of an airship could be a "suction cup" system replacing the mast.[11] See Figure 3-34. The suction cup being the airship landing gear, secure against a turntable on rails. The turntable will accommodate positioning into the wind of the airship at changes in wind direction. The turntable should be motorized and automatically controlled by sensors.

C-2

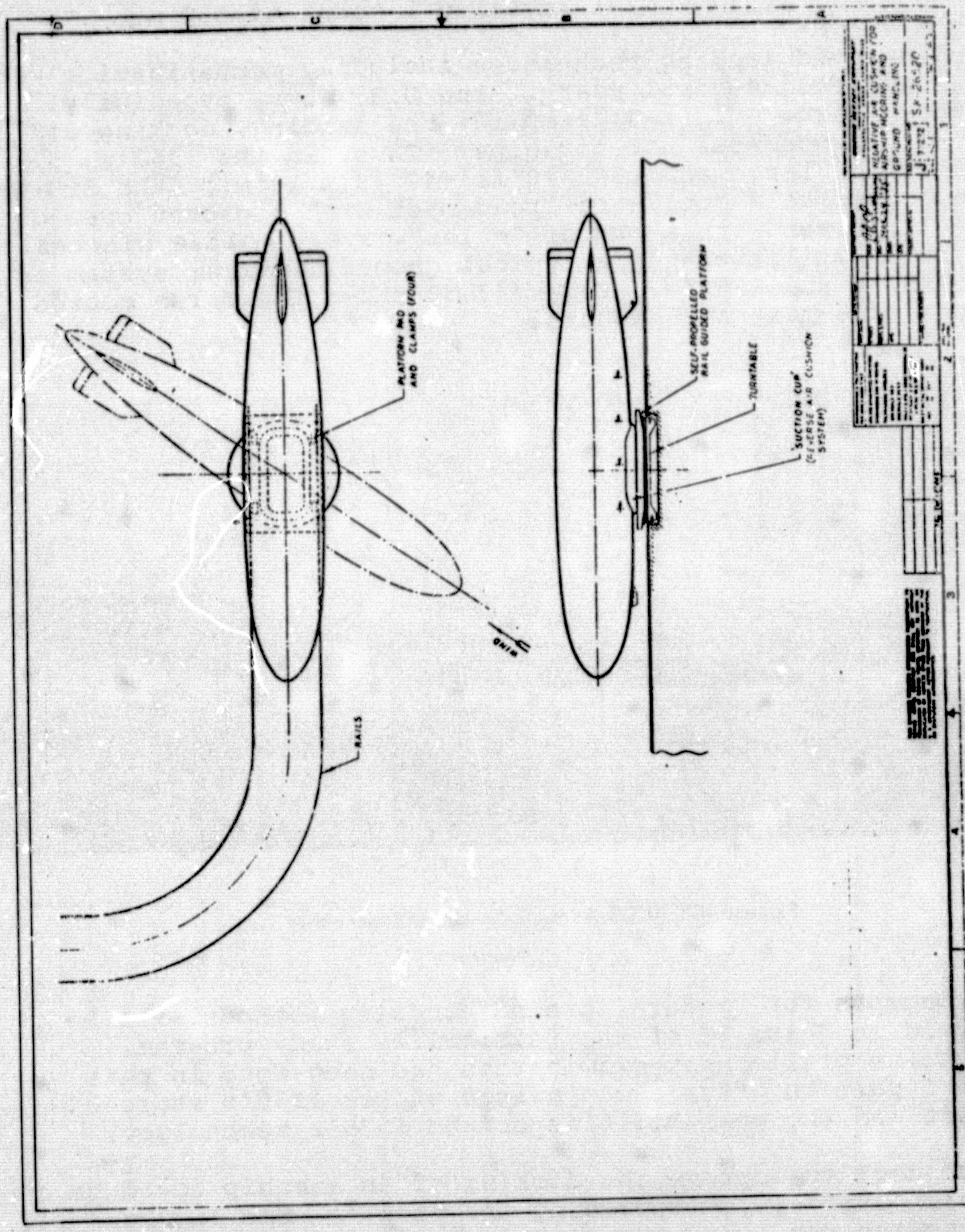


Figure 3–34. "Suction Cup" Landing Gear

Accidents happened in the past when the airship was brought in or out of the shed or hangar. A wind gust would blow the airship against the door opening and damaged the structure or envelope. Such accidents happen also today with the blimps; single cell gas containers get punctured and deflated.[37]

The problem of wind sheers could be minimized by shortening the time the airship is exposed to the two conditions - no wind and wind. One concept could be a vertical entrance and exit from an underground hanger as illustrated in Figure 3-35. Today's vastly improved blasting and concrete construction techniques may further lower the construction costs for the required huge hangars. A fully buoyant airship should be hauled down by winches into the hangar; a VTOL hybrid airship could possibly enter under its own power.

In summary, with the 1975 technology it will be possible to improve the operational procedures for an airship in flight as well as on the ground.

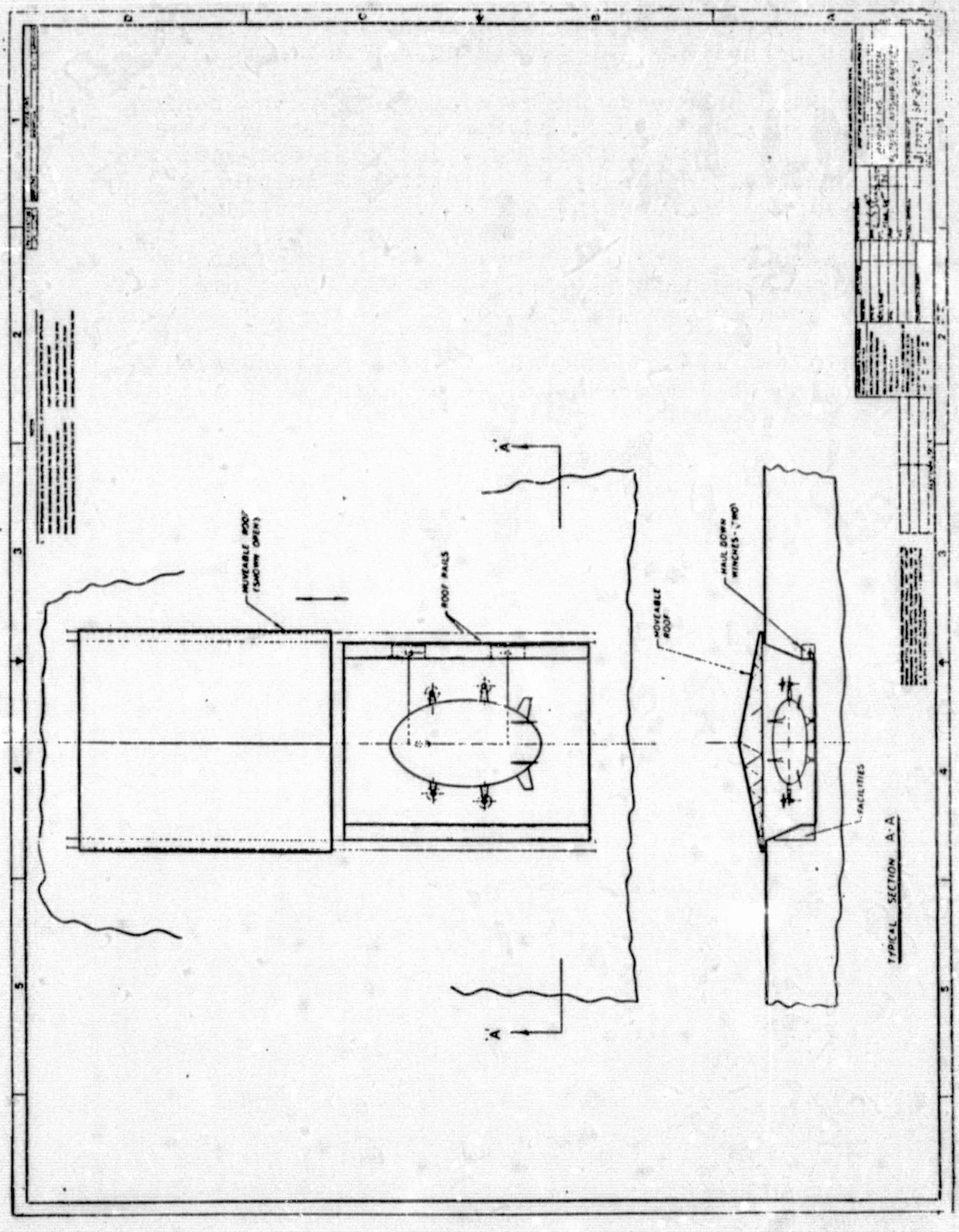
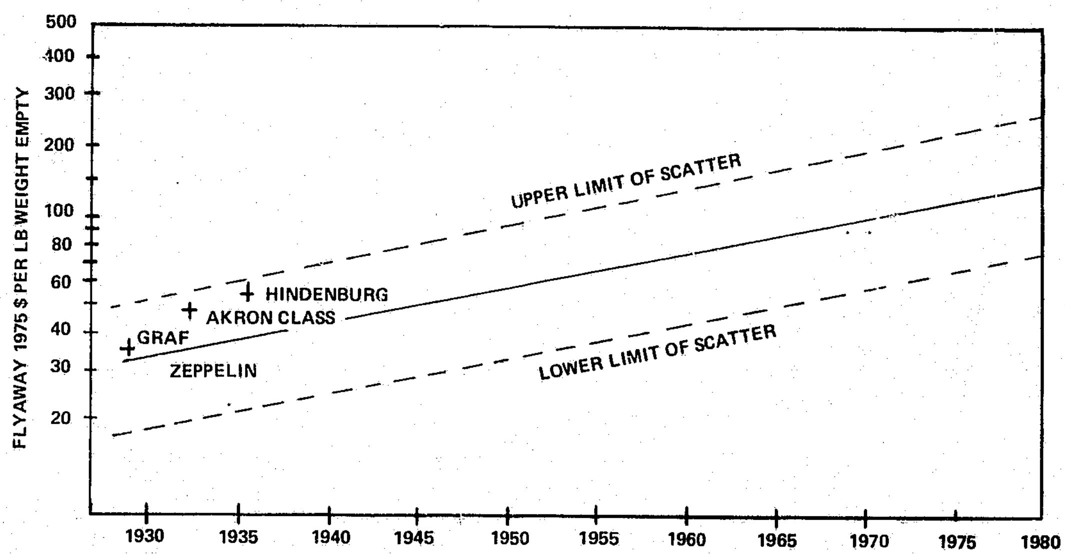


Figure 3–35. Future Hangar Concept.

3.2.7 Economics

When comparing the 1930's and 1975's technology, the costs of the advancement must also be considered. With the increased understanding of the problems and with methods now available to test and verify a design, the costs have increased. Of course, the increased cost pays for higher safety and better reliability, which should result in lower ownership costs.

The difference in cost between a 1930's design of an airship and a 1975's, can be determined from Figure 3-36 which shows a plot of the increase over the years due to the advancements in the state-of-the-art in 1975 dollars. The plot has been developed from actual data on fixed wing aircraft.[64]



Conversion factor: $ per lb = 2.2 $ per kg

Figure 3–36. Increase of Flyaway Cost per Pound Weight Empty vs Time

The flyaway cost in 1975 $ per lb weight empty for three rigid airships[3] have also been plotted in the figure. As can be seen they all fall within the scatter band. There is no reason for not believing that an airship would not follow approximately the trend of a fixed wing aircraft. The technology and principles of design is the same in the majority of the overall construction (which includes all subsystems and equipment).

Consequently, Figure 3-36 tells that the Graf Zeppelin if designed and fabricated in 1975 should cost 1975 $ 17,620,000 in flyaway cost; the Hindenburg 1975 $ 44,000,000; the Akron 1975 $ 51,000,000. The higher cost for the Akron, which was only 8% smaller in volume than the Hindenburg, reflects the

traditionally higher cost of production in the U.S.A. when mass production is not used.

In lack of better airship data which cannot become available until a detail design study has been made and costed, a task which is beyond Phase I study as well as Phase II, the presented data on 1930 and 1974 state-of-the-art cost must serve as guidelines

Another interesting plot is Figure 3-37, manhours per unit weight empty. Several fixed wing aircraft of varying complexity has been plotted. Available data on the Akron and Hindenburg[3] are also shown. They fall well within the wide band of fixed wing data. The difference between Akron and Hindenburg can be explained by the fact that Akron was more complex as being a military vehicle (hangaring, launching and retrieval of fighter aircraft, for example). Also, the construction of the Akron did not have the many years of experience in construction of rigid airships behind it as the Hindenburg had.

Direct operating costs of a 1975 airship cannot be estimated until more detail study, called for in Phase II of the feasibility study of modern aircraft, has been conducted.

The 1930's direct operating cost[3] (as far as it has been possible to determine from the limited information available) are presented in Figure 3-38. The D.O.C.'s for airplanes in the same era have been plotted for ready comparison.

The 1975 operating costs for an airship cannot be deduced from the 1930's data. The impact of automation, improved vehicle configurations, federal regulations, etc. must first be established.

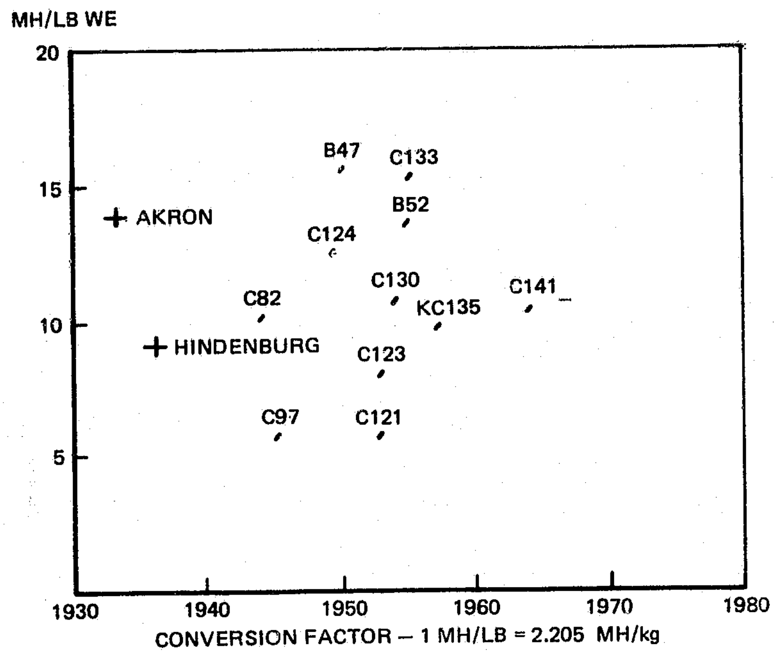


Figure 3–37. Manufacturing Manhours per Pound Weight Empty, Airplanes and Airships

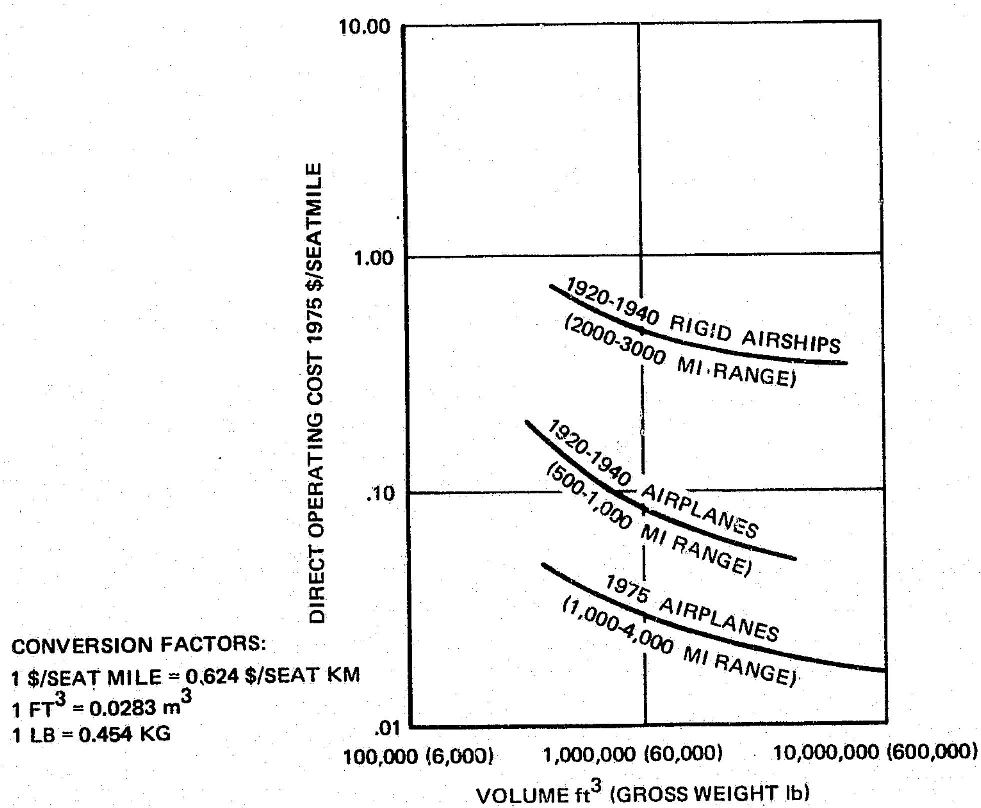


Figure 3–38. Rigid Airship Operating Cost Trends

In conclusion: A modern airship will most probably be more expensive in development as well as flyaway cost than its 1930's counterpart. On the other hand, this higher cost will buy increased safety and reliability which may reduce the inflation rate for ownership cost. Direct operating costs may be higher than what the normal rate of inflation would encounter for fuel prices have, for an example, been sky-rocketing beyond normal expectations. On the other hand, the 1975 state-of-the-art in automation would reduce the manning requirement for a mdoern airship and may, therefore, offset the increases above normal inflation.

4. TRANSPORTATION SYSTEMS SURVEY

A general screening of the whole transportation market was first done to isolate sectors where an LTA vehicle could be expected to find a slot. The section of transportation and missions which were selected for an analysis are shown in Figure 4-1 which also presents a brief summary of the conclusions.

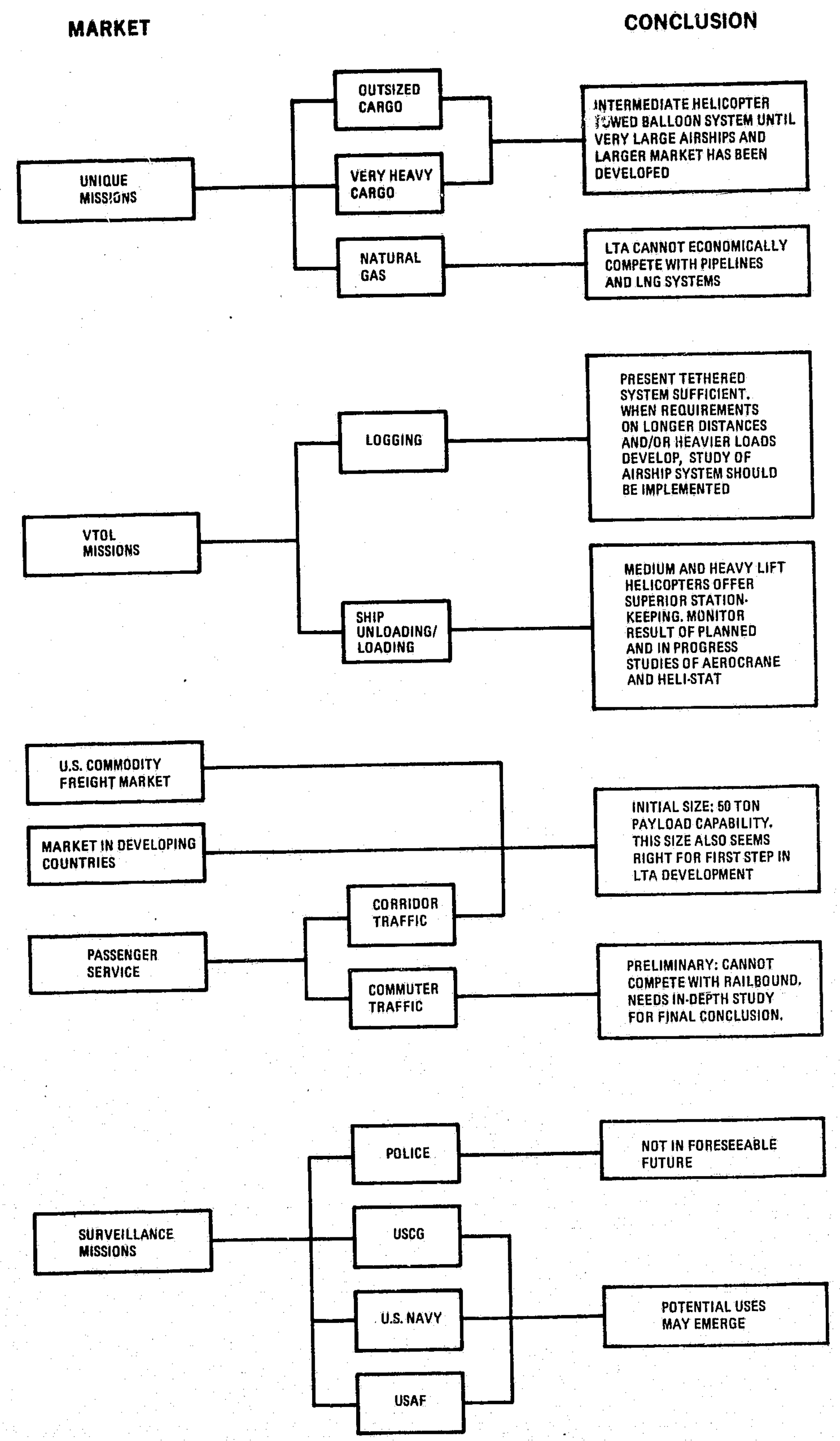


Figure 4–1. Summary of Mission Survey, Approach and Result

4.1 Summary and Conclusions

A certain section of the transportation market, namely, delivery of heavy and especially voluminous factory made components, to the construction site could today favorably utilize an airship design.[11] The "very oversized" goods started to come with the huge power generation stations, not only the nuclear type but also fossil plants. Larger construction components within industries, such as bridge building, transmission powerlines and pipelines, shipbuilding, house constructions, etc. may also come in the future providing suitable means of transportation are available from the factory to the construction site. Presently, the designs of the individual pieces consider the possibilities of transportation and thus limit the size. In many cases, it would be more economical to replace on-site assembly of several small components with a factory manufactured very large component.

Present market of unique missions for an airship of a 800 ton payload vehicle is very limited. A utilization of one airship only, can be estimated at about 600 hours a year. That kind of utilization cannot pay for the production cost of a 50×10^6 ft^3 (1.4×10^6m^3) airship, still less for the development costs.

The present problem with transportation of huge powerplant components and the excessive transportation costs could be solved with a helicopter towed balloon system as outlined in Paragraph 4.4. The transportation by such a system would many times be less expensive than present earthbound transportation and thus help to reduce the costs in construction of much needed energy generating plants. A Very Heavy Lift balloon system could be developed in a rather short time and at a reasonable cost because of the low technical risk involved as well as simplicity. Further, the appearance of a VHL transport system may develop the interest with other manufacturers of large components and plants to consider more economical factory made pieces. Thus, the market will be built up for a future large airship.

In search for a transportation market that could justify a revival of the airship, an investigation of the U.S. Freight Commodity Market was made. An airship size of about 50 tons payload capacity seems to be optimum. 0.5% of the estimated 1985 transport requirement would require 43 up to 87 vehicles with a utilization of 4,000 to 2,000 hours per year, respectively. 2% of the market would require from 174 up to 348 airships.

Transportation of natural gas in gaseous form by pipelines as well as liquefied in tankers are very cost-effective means of transportation. Although analyses of development costs and production costs of an actual gas carrying airship (the fail-safe containment of the flammable gas must be considered) were not within the scope of this conceptual study, it is apparent, by comparing the what-it-can-cost figures in Paragraph 4.5 with the discussion of economics in Paragraph 3.2.7 that an airship cannot successfully compete with present well-developed systems.

The passenger traffic in the U.S. West Coast corridor between San Francisco-Los Angeles-San Diego has been examined. This investigation indicates there are segments which offer a potential for an LTA vehicle of the 50 ton/250 passenger payload capacity with a cruise speed of at least 100 kt (51.4 m/s) and VTOL or STOL capability.

A brief comparative analysis between a commuter traffic airship system and a modern railbound system indicates that the airship may not be a competitive alternative. A more thorough analysis which should go more into detail than could be done within the scope of the Phase I conceptual study, should be made for a definite conclusion on this application. Such a study must address the full complexity of the installation of a new railbound system, an airborne system, airship development costs, airship certification, production, flight rules, all-weather operation, etc.

Potential U.S. Coast Guard surveillance missions have been defined and the required LTA vehicles have been sized in the computer program and considered in the Vehicle/Mission Matching and Selection, Paragraph 6.2.

A near future use of LTA vehicles in police traffic and law enforcement work cannot be foreseen. An LTA vehicle cannot compete cost-wise with a helicopter. Further, no requirements for a very long endurance surveillance vehicle which could require a remotely piloted vehicle exists. The acceptability of an unmanned, relatively large LTA vehicle loitering over populated areas is uncertain.

U.S. Navy missions in the surveillance field and a U.S. Air Force missile mission emerge as potential candidates for an LTA vehicle. Further work on definition of an LTA configuration should consider a matching of commercial missions and military to achieve a common size of the platform - the LTA vehicle.

In conclusion, the survey of transportation missions indicates that the first development step should be an approximate 50 ton payload airship. That size could find a market in commodity freighting as well as passenger service. Further, it seems to be an approximate size for research and development of improved subsystems as well as larger sizes. Large size LTA vehicles (10×10^6 ft^2 (283×10^3m^3) and up) will be rigid (see Paragraph 5.3.1.1), fully buoyant or partial buoyant configurations. Therefore, very little, if anything, can be gained by starting a step development program with a non-rigid airship, although some limited recent, operational experience exists. Too small a size of the first-step development airship will deceive the purpose and acceptance due to incapability to show useful performance.

The limited transportation problem with bulky cargo, requires such large airships that sufficient utilization is not here. Further, such a size will take several development steps to materialize. To solve the present problem, an intermediate helicopter towed balloon system is recommended to be developed. Such an undertaking must, however, be preceded by an in-depth analysis.

4.2 U.S. Freight Commodity Market

The present and projected transportation system for freight commodity within the U.S.A. has been analyzed to determine what segment would have a potential application for an LTA vehicle.

Data available on this market are the 1967 Census of Transportation, Commodity Transportation Survey prepared by the Bureau of Census, Department of Commerce.[26] The prime objective of these surveys is to measure the transportation and geographic distribution of commodities shipped by manufacturing establishments in the United States beyond the local area; it does not include data for agricultural commodities.

Other data used were the Freight Commodity Statistics for Motor Carriers of Property (1972)[27] and Class 1 Railroads (1973)[28] issued by the Interstate Commerce Commission, Bureau of Accounts. These data are for Class 1 motor carriers defined as those with average annual operating revenues in excess of $1 million.

Industry Profiles 1958-1969[29] issued by the Bureau of Domestic Commerce, Department of Commerce were used to estimate the growth of commodity shipments and shipment values.

Railroad freight costs vary from 3 to 4 cents a ton-mile and motor carrier from 7 to 10 cents a ton-mile. Motor carriers are used because they are quicker and more reliable and they

do not involve a change of mode, i.e., they can transport freight from door to door.

It was concluded that commodities that were transported mostly by motor carriers would be better suited to the airship on the basis that those commodities could tolerate a cost per ton-mile over twice that of railroads for benefits that would be present in an LTA vehicle, i.e., door to door service (VTOL capability), lower journey time and higher reliability.

The low cost of the railroad is also the reason for its long delivery time. Freight railcars have to be loaded at separate yards then collected to make one long train. This adds non-movement time but reduces crew and fuel costs. Similar delays are present at the destination where railcars have to be dispersed to their respective yards.

Further delays arise because of transferring cars from one railroad to another and to shipments that have to complete their journey by truck at each end.

This also has been one of air freights' most intractable problems, the ground processing of freight since goods may spend as long a time on the ground as in the air. The payload of freight aircraft range from about 50 tons (Boeing 707) to about 130 tons (Boeing 747) but about 80% of air shipments are 100 pounds or less, resulting in high processing and collecting costs.

Even in motor carriers, the cost of terminal operations has been increasing at a faster rate in the last 10 years than the cost of longer haul intercity operations.

There are nearly 500 different commodities listed in the Bureau of Census and Interstate Commerce Commission statistics. These were examined to determine in which of them 60% of the tons or more were moved by road. In total 72 commodities were isolated, representing over 50% of the total tons moved by road and 13% of the total tons moved by both modes. These 72 commodities were reduced by eliminating those that had less than one million tons per annum; further reductions and additions were introduced due to data availability and/or high percentage of tons moved by modes other than rail, resulting in a total of 27 commodities listed in Table 4-I.

The growth rate per annum of the shipment of each of these commodities was obtained from Industry Profiles 1958-1969[29] and used to project the tons and ton-miles (assuming a constant distance distribution) to the year 1985.

Table 4–I. Commodity Transportation Statistics

**TCC No.	Item	Transported Quantities				Average Miles
		1967 Data		1985 Estimates		
		*Tons x 10^3	*T-Miles x 10^6	Tons x 10^3	T-Miles x 10^6	
2012	Meat Fresh Frozen	630	518	1,237	1,017	822
207	Confectionary	2,557	2,234	5,745	5,019	874
2096	Marg & Other	1,545	1,109	2,654	1,905	718
283	Drugs	1,912	1,073	6,354	3,566	561
284	Soap & Dets.	4,192	3,074	15,780	11,645	733
349	Misc. Fab Metal Prod.	2,453	2,135	9,617	7,848	870
353	Mat. Handl. Equip.	3,578	3,201	13,599	12,166	895
359	Misc. Mach. & Parts	909	617	4,432	3,008	679
369	Misc. Elect. Equip.	740	397	3,268	1,753	536
	Total	18,516	14,358	62,186	47,927	
		1972 Data		1985 Estimates		
222	Manmade Fiber	618	462	1,859	1,388	748
225	Knit Fabrics	397	317	998	797	798
227	Floor Coverings	2,781	2,158	11,844	9,191	776
228	Thread & Yarn	1,109	722	2,693	1.753	651
231	Men's Clothing	952	819	1,867	1,606	860
233	Women's Clothing	995	656	1,853	1,222	659
239	Misc. Textile Prods.	1,006	807	2,974	2,386	802
306	Misc. Fab., Rubber	895	752	1,811	1,522	840
307	Misc. Plastic Prod.	3,985	3,404	18,845	16,106	855
332	Iron, Steel Casts	2,235	1,382	5,790	3,580	618
335	Non-Fer. Basic Shapes	7,954	6,272	22,978	18,119	788
336	Non-Fer. Castings	654	570	1,907	1,685	884
339	Misc. Metal Prod.	1,319	841	4,093	2,610	638
321	Flat Glass	875	587	1,796	1,205	671
322	Glass Blown	3,157	1,773	7,418	4,166	562
325	Stu. Clay Prod.	5,469	2,628	9,003	4,326	480
326	Pottery	511	471	910	839	922
327	Concrete, Plas. Prod.	4,803	2,605	9,165	4,971	542
	Total	39,704	27,226	107,802	77,472	
	Grand Total			169,988	125,399	

* To obtain International System Units:

Tons x 907 = kg
T-Miles x 1.459 = Metric T-km

**Transportation Commodity Code

ORIGINAL PAGE IS OF POOR QUALITY

The data was reduced by eliminating those tons and ton-miles that were moved over stage lengths less than 300 miles, it being contended that the truck would have adequate journey time at those stage lengths.

This resulted in a total of 125,399 million ton-miles required in the year 1985. Table 4-I also details the average distance in miles that each of these commodities was transported, obtained by dividing the ton-miles by the tons. The distribution around those average distances has not been determined.

Of the 27 commodities, an analysis of the weight of individual shipments reveals that 80% of them weigh 45 tons or less; this is higher than a road truck (30-40 tons) but less by about 10 to 20 tons of that of a railroad car.

Table 4-II details additional features of these commodities; the value of the shipments was obtained from Industry Profiles 1958-1969[29] for the relevant years, 1967 or 1972, dollars per pound from dividing this by the Bureau of Statistics Commodity Transportation Survey[26] total tons for each commodity and the percentage moved by road and air from the same source. Tons per carload was obtained by dividing the total tons by the number of carloads obtained from the Interstate Commerce Commission Freight Statistics.[27] The average miles were obtained from the Bureau of Statistics data as for Table 4-I; however, the below 300 miles stage lengths are included in Table 4-II. Dollars per carload was obtained by dividing value of shipments for Industry Profiles 1958-1969 by the number of carloads and the cents per ton mile by dividing this by the average miles.

While the absolute values of the ratioed data in this table are not considered accurate and hold many inconsistencies because of the different data sources, the data gives a rough approximation of the value per pound to produce the commodity and the cost per pound to transport it. Other data giving the price per unit which the market will bear, i.e., the elasticity of demand could be generated to further define those commodities which could be viable candidates for an LTA transport system.

Table 4—II. Commodity Transportation and Cost Statistics

TCC No.	Item	Value $M	Value *$/lb.	% by Weight Road	% by Weight Air	Road Transportation Cost *Tons/ Carload	* Miles	$/ Carload	*¢/Ton Mile
2012	Meat Fresh Frozen (1)	15,576.3	5.55	86.7	-	17.94	498	653	7.3
207	Confectionery	2,694.6	0.31	73.3	-	15.73	575	435	6.4
2096	Marg & Other	1,725.6	0.24	70.2	-	18.69	391	341	4.7
222	Man-Made Eiber	4,006.0	1.35	94.9	0.1	13.52	384	370	7.4
225	Knit Fabrics	6,911.2	3.73	98.7	0.2	10.76	415	385	9.3
227	Floor Covering	3,373.4	0.46	80.9	0.1	12.20	630	502	6.5
228	Yarn & Thread	3,671.3	0.55	95.5	-	13.40	333	315	7.1
231	Men's Clothing (2)	2,677.8	0.70	89.5	1.8	9.25	591	523	9.6
233	Women's Clothing	8,531.4	2.77	88.8	3.8	8.57	487	447	10.7
239	Misc. Textile Prods.	2,904.7	0.85	70.7	0.3	12.78	550	434	6.2
283	Drugs	5,301.6	1.56	68.3	1.2	14.96	740	460	4.2
284	Soaps, Det., Etc.	7,126.0	0.37	74.4	-	16.22	428	333	4.8
306	Misc. Fab. Rubber	4,160.7	2.38	86.6	0.8	13.16	479	417	6.6
307	Misc. Plastic Prod.	10,000.9	1.25	82.9	0.3	11.54	516	436	7.3
332	Iron & Steel Castings	6,255.1	1.40	76.4	-	16.64	275	306	6.7
335	Non-Fer, Basic Shapes	14,828.0	0.93	63.5	0.1	15.82	454	446	6.2
336	Non-Fer, Castings	2,818.8	2.18	69.6	0.2	14.56	455	390	5.9
339	Misc., Metal Prods.	3,145.2	1.19	63.4	0.1	17.76	346	295	4.8
321	Flat Glass	857.1	0.49	73.4	-	17.50	433	413	5.4
322	Glass Pressed & Blown	3,274.5	0.52	88.9	-	14.67	259	271	7.1
325	Stu., Clay Prods.	1,202.6	0.11	74.5	-	18.97	217	272	6.6
326	Pottery	749.3	0.73	84.9	0.2	14.42	623	523	5.8
327	Concrete, Plaster Prod.	6,642.6	0.69	81.6	-	21.76	148	175	5.4
349	Misc. Fab. Metal Projs.	4,756.6	0.96	62.1	0.3	13.58	510	377	5.4
353	Mat. Handling Equip.	7,865.0	1.10	54.8	0.3	15.94	662	534	5.1
359	Misc. Mach. & Parts	3,712.0	2.04	91.7	1.3	13.20	394	530	10.2
369	Misc., Elect Equip.	2,773.7	1.87	89.7	0.6	12.42	373	495	10.7

Air is less than 0.1% of total in the following: 228; 332; 321; 322 & 325.

(1) Industry profiles shipment values are for TCC No. 201 Meat Processing Plants which is probably why the cost per pound of this item is too high.

*) To obtain International System Units:

$/lb X .4536 = $/kg

Tons/Carload X 907 = kg/carload

Miles X 1.609 = km

¢/T-Mile: 1.459 = ¢/Metric T-km

ORIGINAL PAGE IS OF POOR QUALITY

Table 4-II shows that air transport has been able to obtain from 0.1% to 3.8% of the transport market of these commodities. (In some regions the percentage is considerably higher, as much as 6%.) An LTA vehicle would have the door-to-door capability of the road vehicle, a possible five to six times speed advantage and if it was sized to minimize the processing and collection of freight, it could be expected to penetrate this market, if its cost of transportation was equal or less than that of air freight, 20 to 25 cents a ton-mile.

Table 4-III has postulated a 50 ton payload airship with at least 100 knots (51.4 m/s) cruise speed obtaining a 60% load factor and utilization of 2000 hours and 4000 hours a year operating in this market. Four market shares have been assumed, 0.1%, 0.5%, 1.5% and 2%; these values appear to be possible on the basis of air freight experience.

The number of airships required varies from 9 to 348 depending on market share. With a price of 15 cents a ton-mile, related to the 2% market share and 24 cents to the 0.1% (these values are purely arbitrary) market share, the direct operating cost of the airship with a 1 cent a ton-mile for indirect costs and a 5% margin for reserve/profit lie between $487 and $774 an hour.

This isolation of commodities that are candidates for transport by an LTA vehicle has not been exhaustive and has not included agricultural products which would represent a large market, especially in the transport of perishable foods across country. A cursory examination indicates that these 27 commodities represent about a quarter of the total potential of airship application, 14% of all road freight and 3% of the total freight moved.

It is concluded, therefore, that a 50 ton payload airship with at least 100 knots (51.4 m/s) cruise speed and with the capability of flying across country non-stop has a potential in the commodity transportation market, provided it has VTOL or at the least good STOL capability and can operate at a profit with a freight rate of between 15 and 25 cents a ton-mile.

The present analysis has confined itself to the freight market inside the United States; however, the 50 ton payload LTA vehicle would have a potential export market and could satisfy the requirements of the developing countries outlined by Mr. G. J. Beier and G. C. Hidalgo of the International Bank for Reconstruction and Development.[11] It could also have an application in the transport of pineapples and bananas from Hawaii and islands further west where the transport of these perishables is causing the shippers to seriously re-evaluate the current transportation mode and seek a system with a shorter delivery time.

Table 4–III. Number of 50-Ton Payload Airships as a Function of Market Share

Total Ton-Miles (1985) $= 125{,}399 \times 10^6$ Ton-Miles

Annual Airship Potential = Payload (50 Tons) X Load Factor (60%)
X Speed (120 mi/hr/100 kt/51.4 m/s)
X Annual Utilization
(2,000 Hours and 4,000 Hours)
$= 7.2$ to 14.4×10^6 Ton-Miles

Market Share %	0.1	0.5	1.5	2.0
Ton-Miles (1985) x 10^6	125.4	627.0	1881.0	2508.0
Number of Airships				
2,000 Hours/Year	18	87	261	348
4,000 Hours/year	9	43	131	174
Freight Revenue				
Cents/Ton-Mile	24	21	18	15
Millions of Dollars	30.10	131.67	338.58	376.20
Fleet Hours - x 10^6 (1)	35.3	170.59	511.76	682.35
Revenue $/Hour	853	772	662	551
Less %5 (2)	810	733	629	523
Less Indirect (3)	774	696	592	487

(1) Contains 2% nonrevenue flying
(2) Reserve or profit
(3) Taken as 1 cent per ton-mile

To obtain International System Units:

Ton-Miles X 1.459 = Metric T-km

Ton X 907 = kg

4.3 Unique Missions

Particular unique missions that have been suggested for an LTA vehicle have been the movement of large indivisable loads which are precluded from movement by normal surface means because of the size or require devious routes and the possible provision of additional or modification of existing road structures. There also appear to be economies in certain other large products if they could be assembled in plant and transported to the site (houses, electrical transmission towers, bridges, highway overpass structures are examples of these). The logging industry has also used tethered balloons and helicopters to transport logs and has indicated an interest in a higher lift capability which could be an LTA vehicle.

The movement of the components of nuclear powered electrical generating stations would require a payload of up to 800 tons (reactor vessels and steam generators)[11] which would probably be also adequate for bridge and highway overpass structures. A block speed of about 25 knots (12.9 m/s) would probably be adequate.

The movement of completely assembled one-family houses and apartment building modules could be satisfied in most cases with a lift capability of 50 tons and transmission tower and logging requirements would be within the range of 10 to 20 tons.

Analysis of the requirements for the movement of large components of nuclear powered electrical generating stations proposed from 1978 to the year 2000, which were remote from navigable waters,[11] indicated a requirement of 4.53 million ton-miles in 1978 to 7.64 million ton-miles in 2000. For an LTA vehicle with a 800 ton payload capability and a 20 knots (11.2 m/s) block speed and assuming a 50% load factor, this would represent an annual utilization of 453 to 764 hours a year for one airship. It is possible that the utilization is underestimated as there would be some non-revenue flying and positioning flying and instead of transporting these components from the nearest navigable waters they would be transported from the plant to the site (this might reduce the total ton-miles); however, it has been assumed that all the components have been transported by the airship which is an overestimation.

In any event, it is unlikely that one 800 ton airship flying 1000 hours a year would not be able to more than satisfy this market. Estimates of other applications of this 800 ton LTA vehicle have not been examined in detail but it is considered unlikely that they would add significantly to this level of utilization until the market has been gradually developed by actual proof of the economical advantages that can be achieved by using an airship.

If an 800 ton payload vehicle were introduced into the commodity transportation market detailed in the previous section, the number of LTA vehicles would be reduced from 9 to 1 at the low end and from 348 to 22 at the high end (see Table 4-III) and would markedly suffer from the disadvantages of the processing and collection of shipments to fill such a large payload.

The 50 ton LTA vehicle postulated in the examination of the commodity transportation market would adequately meet most of the other particular applications identified.

Many unique uses for the helicopter in commercial applications have been postulated in the past because of its VTOL capability and some have come to fruition, in particular in logging, movement of pieces of engineering equipment onto high structures, in electrical transmission lines and in personnel movement onto off-shore oil rigs. All the types being used have had a military market base to offset their development costs. Even so, the marketing of a large heavy lift helicopter, the Sikorsky Flying Crane, S-64, while it has been actively pursued for over 15 years, has results in sales and leases of less than 10 aircraft.

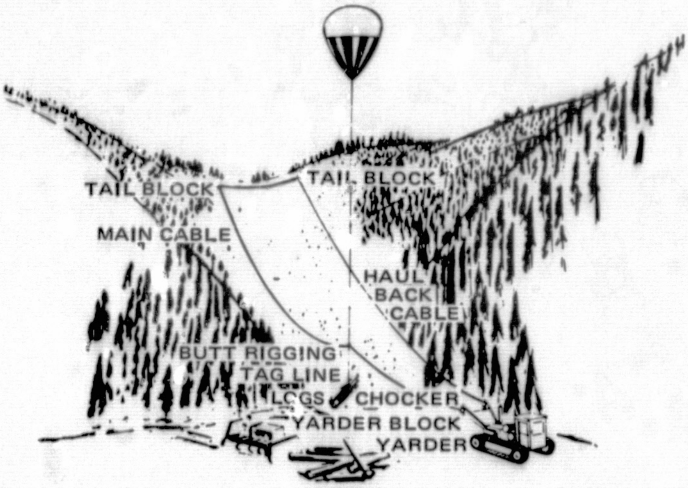
This experience cautions the development of a first LTA vehicle that does not have a broad based market. Also, the development cost and technical risk associated with an 800 ton payload vehicle are much higher than a 50 ton payload vehicle. For these reasons it is considered that the 50 ton payload airship with at least 100 knots (51.4 m/s) cruise speed is a better candidate for development of the first modern airship. This size would be suitable for a research and development vehicle as well as for commercial use.

4.4 Very Heavy Lift Missions

Several applications of airship to "crane" missions have been suggested by practically everybody who advocates a revival of the airship. Such missions, most of them falling in the very heavy lift category, include construction work (buildings, bridges, power lines, pipelines, etc.), ship unloading/loading, strip mining, oil shale cracking, logging, timber harvesting, oil exploration, transport of space shuttle booster, thermal power generating plant components, factory assembled houses, etc. Many of these missions do not require high forward speed. Some require a relatively exact stationkeeping-over-a-spot capability. Here concepts like the Aerocrane (All American Engineering Co.) and the Heli-Stat (Piasecki Aircraft Corp.) could be suitable, although there would be a long development time until very heavy lift capabilities in the 800 ton class could be operationally available.

Balloon logging is now being successfully used, although not yet with very heavy lift capabilities. The system with unmanned aerostat, tethered to a cable being reeled back and forth between two winches, could be developed into higher capacities as and when required by the logging and timber harvesting industry with relatively low technical risk.

Figure 4-2 shows one of the latest developed balloons by Raven Industries, Inc. for logging operations.



RAVEN'S 530,000 f^3 (15,010 m^3) LOGGING BALLOON

Figure 4–2. Ballon Logging

It will be a long time until an 800 ton payload airship of approximate 63 x 10^6 ft^3 (1.28 x 10^6 m^3) volume (if conventional) for transport of bulky cargo such as nuclear power plant components[11] will be available. It is most likely that a gradual growth of the size of airships will take place. This will reduce the risk and would also allow the transport market for airships to accommodate itself and grow so that it is ready to use the larger airship at an economical utilization factor.

Meanwhile, another simpler concept can be visualized for the very heavy payload transport. Such a transport would be at a low speed and be a fair-weather mission. Still it would considerably simplify the transport by passing over obstructions like bridges, power lines, etc.

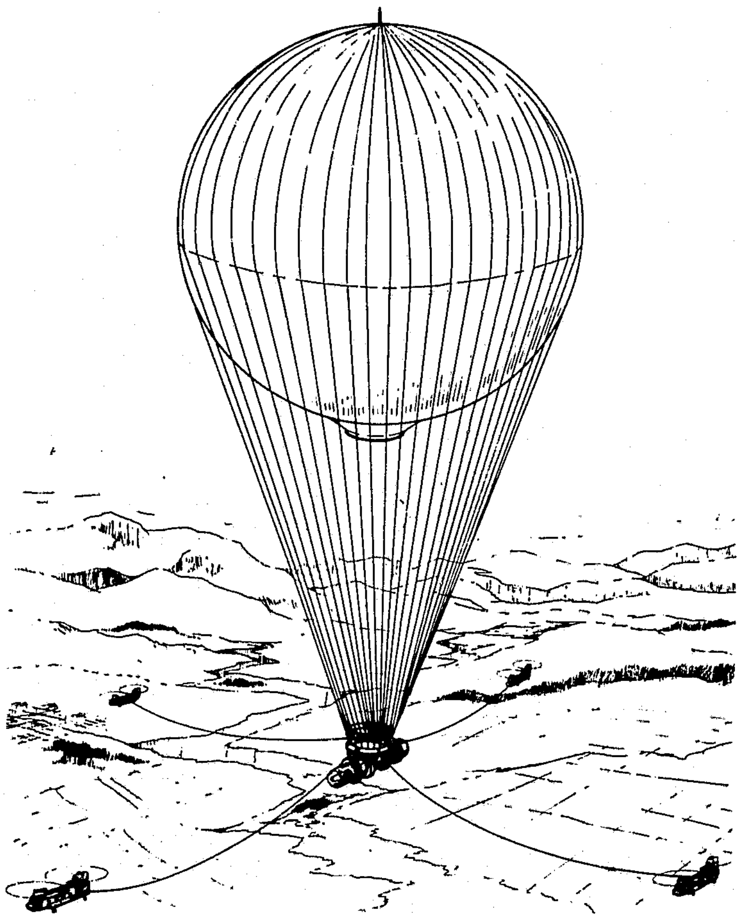


Figure 4–3. Towed Balloon Very Heavy Lift Transport System

Figure 4-3 shows an artist's sketch of a towed balloon transport system. The cargo is securely attached to a large balloon supplying required static lift which can be remotely controlled by ballast, gas valving, or any other lift control systems which may be developed. (A spherical shape in lieu of the elongated shape mostly used for unmanned aerostats will be less costly and is further acceptable due to the low airspeed, fair-weather operation.) Propulsive force and steering is supplied by four (or less) helicopters. Figure 4-4 is a plot of required towing force for different sizes of load at varying airspeeds. The towing capability of different size helicopters is also indicated.

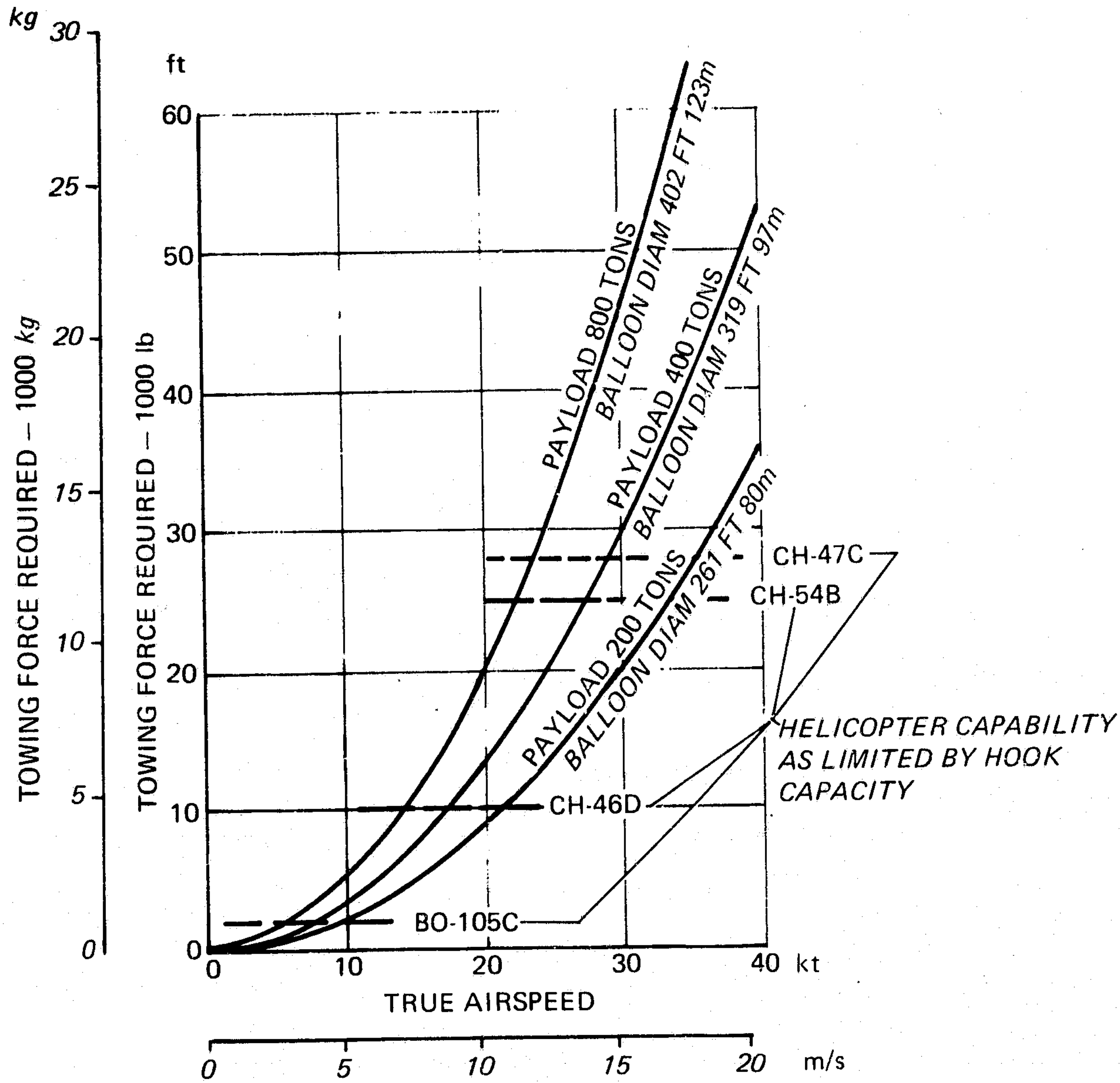


Figure 4–4. Towing Force for Very Heavy Lift Transport System

Helicopter towing of an aerostat with ballast is feasible and has been made for aerodynamic performance tests of the Family II Tethered Balloon System at the Cape Canaveral Air Force Station during late 1973 and early 1974. Figure 4-5, borrowed from Reference 10, shows the configuration flown.

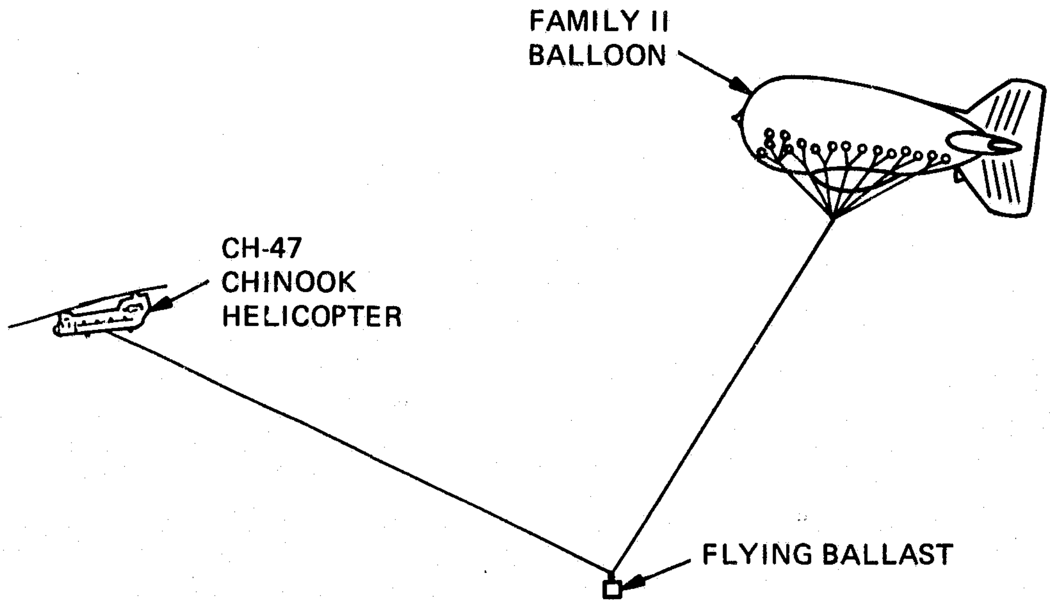


Figure 4–5. Helicopter Tow-Test Configuration

4.5 Natural Gas Transportation

Transport of natural gas from the well to a distribution terminal has been proposed as a potential mission for an LTA vehicle.[11,34,35,36,52] It is an interesting concept from that point of view that the cargo supplies its own lift and can also be used as the engine fuel. The analysis here considers only a fully buoyant airship. An airship with a low buoyancy ratio is out of the question in as much as the cargo is a gas with some lifting capability and as large a volume as possible is wanted. An airship configuration with some heaviness will not change the conclusions. The average natural gas has a lifting capability of 27 lb per 1,000 ft^3 (425 kg per 1,000 m^3). This is too little to lift the weight empty of an airship designed for general cargo and passenger service (see Paragraph 5.2.2). However, an airship for natural gas transportation will be a special purpose vehicle and of a very large volume. By advanced technology it should be possible to achieve for an 100×10^6 ft^3 (2.83×10^6 m^3) a weight empty around 30% of the maximum gross weight/lift. The maximum gross weight/lift defined as the lifting capability with 97% pure Helium. It should be noted that extensive research and development will be required before an airship of such a large volume can be built at the predicted structural weight. It should also be noted that a fail-safe containment system for the natural gas must be developed to prevent any accidents due to the flammability of natural gas. A steam lifting system, if used, will also be the subject for extensive development (see discussion in Paragraph 5.2.2).

A 30% weight empty plus a crew of four and some mission equipment plus fuel with reserve for a 2,600 miles (4,183 km) distance will amount to a weight which just can be supported by $100 \times 10^6 ft^3$ ($2.83 \times 10^6 m^3$) natural gas. See **Figure 4-6.**

The plot also shows required volume of other buoyant fluids, steam, helium and hydrogen, to lift different ratios of mission weights. (The requirements on development of a hydrogen-lifting system is discussed in Paragraph 5.2.2)

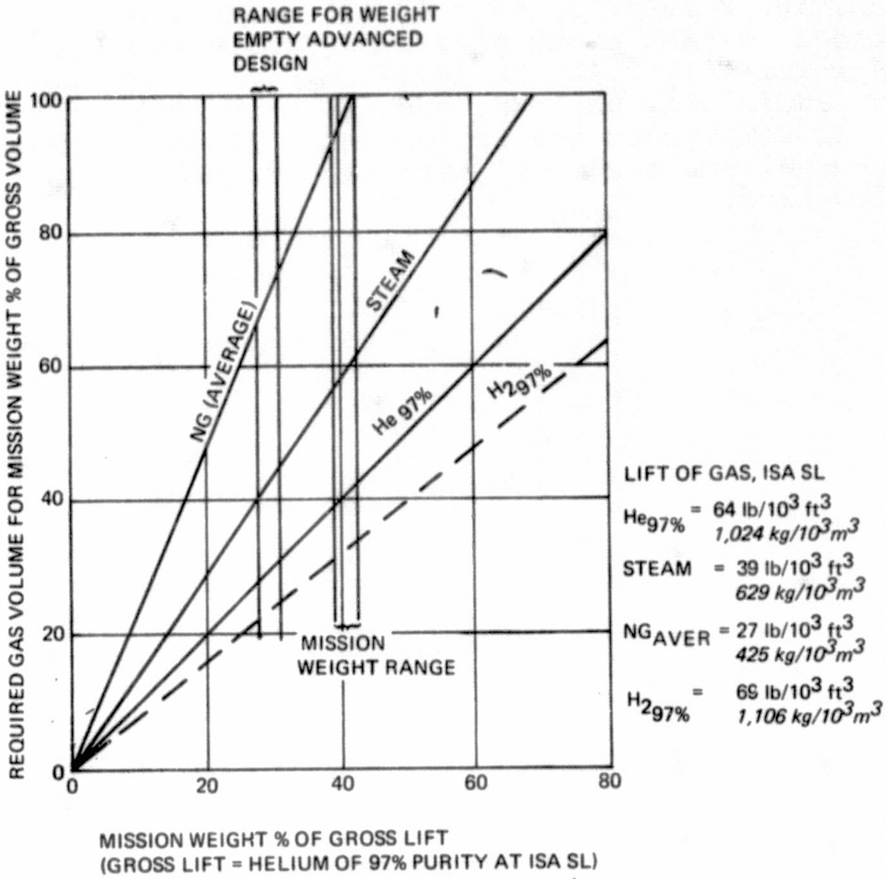


Figure 4–6. Required Gas Volume to Lift Mission Weight of an Airship for Natural Gas Transport 2,600 Miles

Two specific missions have been analyzed to determine the feasibility of using an airship; transport of natural gas over 2,600 miles (4,183 km) and 3,500 NM (6,482 km) ranges. The analyses have been made as a comparison with regular means of transportation; the planned 2,600 mile Alaska natural gas pipeline and a hypothetical liquid natural gas import project analyzed in the Natural Gas Survey by U.S. Federal Power Commission.[53] Inasmuch as development cost, unit cost and operation cost of an airship for natural gas transport cannot be estimated without an extensive preliminary design work far beyond the scope of this conceptual study, the approach has been to establish the allowable competitive cost which must be met by the airship to be in par with other means of transportation. From the costs so determined, it can be easily judged if an airship can be competitive and if transportation of natural gas is a potential airship mission.

Figure 4-7 illustrates the delivered natural gas quantity of a 100 x 10^6ft^3 (2.83 x 10^6m^3) airship as a function of the distance between wellhead and distribution terminal. Using JP-5 as a fuel for the approximately 74,000 HP turboprop

engines, 100 x $10^6 ft^3$ (2.83 x $10^6 m^3$) natural gas can lift the operational weight empty plus fuel (including 10% reserve) for approximately 2,400 NM (4,445 km). At shorter distances, additional payload, such as crude oil, could be carried. This will complicate and prolong the unloading time as natural gas terminal and crude oil terminal probably is not at the same location.

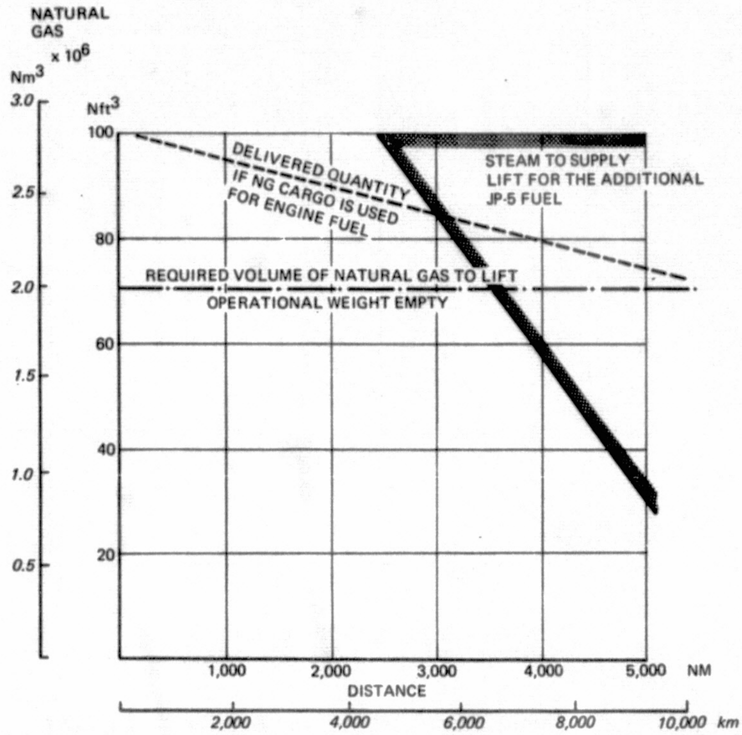


Figure 4–7. Natural Gas, Delivered Quantity by One 100 x $10^6 Ft^3$ (2.83 x $10^6 m^3$) Airships vs One-Way Distance

For longer distances another buoyant fluid must complement the lift. Figure 4-7 shows this additional lift by steam and corresponding reduction in delivered quantity of natural gas.

The natural gas cargo could be used as engine fuel in lieu of JP-5. This will, however, decrease the delivered quantity of natural gas as can be seen from Figure 4-7 up to a distance of 3,000 NM (5,556 km) where it equals the delivered gas volume of a JP-5 burning airship.

Steam as the buoyant fluid to make up for the additional JP-5 fuel load for distances over 2,400 NM (4,445 km) gives more payload (delivered natural gas) than helium, although the specific lift of steam is only 61% of helium of 97% purity. The amount of complementary lifting gas is determined by the return flight requirement. The amount of complementary lifting gas required for this leg is considerably more than required for delivery of maximum volume of natural gas over long distance. The high

cost of helium (and also long-term availability) prevents release of helium when natural gas is loaded. It could be stored, but it is a one-way street with a steady increasing helium storage at the wellhead, where it is not needed. Steam is sufficiently inexpensive (see Paragraph 5.2.2) to be valved off when loading natural gas.

The delivery rate in volume per hour of a 100×10^6 ft^3 ($2.83 \times 10^6 m^3$) airship with a cruise speed of 100 knots (51.4 m/s) as a function of distance is illustrated in Figure 4-8.

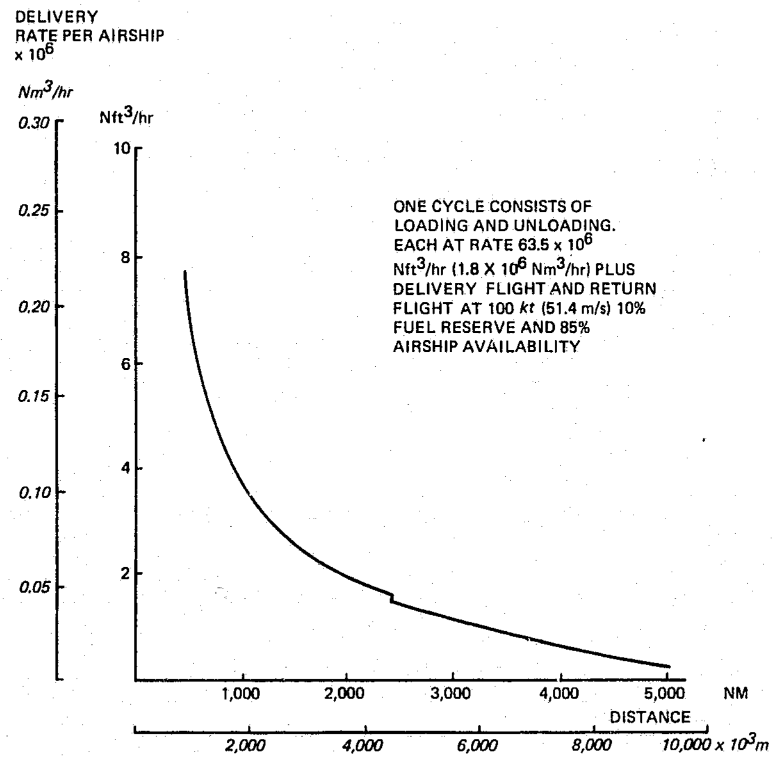


Figure 4–8. Natural Gas, Delivery Rate by One $100 \times 10^6 Ft^3$ ($2.83 \times 10^6 m^3$) Airship vs One-Way Distance

Transport of natural gas by airship does not negate the need for processing plants at the wellheads. Most of the paraffin hydrocarbons (ethane, propane, the butanes, pentane, helane, heplane and octane), plus quantities of sulphur, helium and carbon dioxide, will be removed because of their commercial value. From an LTA vehicle point of view, it should also be done. The specific gravity of the hydrocarbons varies between 1.5 and 2 (air = 1). The boiling point of the butanes falls between 20-34°F (-6 to + 1°C) and propane is -44°F (-42°C). They would easily condense if left in the natural gas. Safe heating of the flammable gas is probably further away from a safe solution than the safe containment system of the natural gas.

4.5.1 Summary and Conclusions

The analyses discussed in following Paragraphs 4.5.2 and 4.5.3 show that

a. To match the proposed Alaska natural gas pipeline, 130 LTA vehicles, volume 100 x $10^6 ft^3$ (2.83 x $10^6 m^3$), cruise speed 100 kt (51.4 m/s) and availability of 85%, will be required, Each airship cannot cost more than $44 million for equal initial investment costs. The total operating cost will be approx. 2.2 times higher than the pumping cost for the pipeline.

   To meet the capacity of the planned Alaska pipeline, one airship must arrive every 26 minutes. There will be a string of airships 43 NM (50 miles) (80 km) apart in both directions, not to mention the crowded situations at the two end terminals.

b. To match the LNG transport system over a distance of 3,500 NM (6,482 km). 24 LTA vehicles, volume 100 x $10^6 ft^3$ (2.83 x $10^6 m^3$), cruise speed 100 kt (51.4 m/s) and availability of 85%, will be required. Each airship cannot cost more than $23 million. The price of the gas at U.S. port, delivered by airship, will be approximately 4 times higher than the LNG gas.

   Every four hours an LTA vehicle must arrive from a 3,500 NM (6,482 km) voyage.

Considering the well developed and highly efficient natural gas pipeline system and LNG system as well, and the maximum allowable airship unit cost for compatibility, it is most improbable that the airship can find a market in the natural gas transportation field. Some very unusual conditions in regard to location of the gas source must be at hand in combination with extremely high prices of all kinds of energy, to make airship transportation of natural gas feasible.

4.5.2 A Comparison With Proposed Alaska Pipeline

4.5.2.1 Baseline

The planned Alaska pipeline "Trans-Canadian Pipeline" for natural gas will have

- a length of 2,600 mi (2,259 NM) (4,183 km)
- a utilized capacity of 5,479.5 x 10^6 N ft^3/day (155.2 x 10^6 Nm^3/day); 228.31 x 10^6N ft^3/hour (6.47 x $10^6 Nm^3$/hour)
- a construction cost of $5,700 x 10^6 (1974 estimate No land acquisition cost in as much as it is Canadian Government land.)

The pumping cost will be \$4.986 million per day; \$207,764 per hour based upon an average pumping cost for existing pipelines in 1974 of 35¢ per 1,000 ft^3 per 1,000 miles (76.8¢ per 100 m^3 per 1,000 km).

4.5.2.2. Loading and Unloading

To establish required time for loading and unloading of the natural gas cargo, the performance of a typical pipeline with the following characteristics was used:

Diameter: 36 in (.914 m)

Average Gas Velocity: 25 mi/hr (11.2 m/s)

Average Pumping Pressure: 1,000 lb/in^2 (689,476 N/m^2)

Thus, loading and unloading will take place at a rate of 63.473×10^6 N ft^3/hr (1.798×10^6 N m^3/hr). 100×10^6 N ft^3 (2.83×10^6 N m^3) will be loaded in 1.6 hours. Unloading will take equal time. Assumption is made that the buoyant fluid for the return flight is inflated and deflated, respectively, during the cargo unloading/loading time.

4.5.2.3 Mission Profile

With the loading and unloading times defined above and a cruise speed of 100 kt (51.4 m/s) the total time for one cycle (delivery flight + return flight) will be 48.4 hours. See Figure 4-9. Servicing of the airship is optimistically assumed to take place simultaneously with loading and unloading.

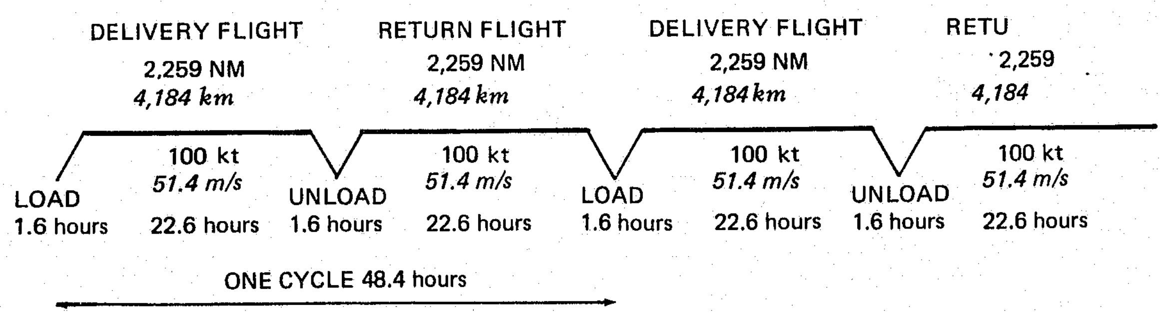


Figure 4–9. Natural Gas Transport Mission Profile (Alaska Line)

The delivery flight is a low altitude flight to facilitate maximum volume of natural gas cargo. The return flight using steam as buoyant fluid requires a gas volume of 60% of the total available volume at sea level. The return flight can thus take place at 12 - 13,000 ft (3,660-3,960 m) altitude (pressure altitude approximately 16,000 ft (4,880 m)) at a lower fuel consumption.

4.5.2.4 LTA Vehicle Configuration and Required Quantity

The LTA vehicle will be of an advanced design with a volume of 100 x 10^6 ft^3 (2.83 x $10^6 m^3$). The advanced design will result in a mission weight which can be supported by average natural gas. There will be no capability for additional payload such as crude oil or LNG. (See Figure 4-5) Such an advanced design and large volume as well will require a great deal of development. It is assumed that the airship will operate with an availability of 85%. The moderate sophistication of equipment and accessories for an airship solely transporting natural gas and the technology in the time period when such an airship can be operational, justifies the assumption of an availability factor of .85. To match the pipeline capacity as stated in 4.5.2.1 Baseline, 130 LTA vehicles will be required.

4.5.2.5 Costs

To be competitive in the first investment cost with the planned Alaska pipeline, the outlined airship cannot exceed a unit cost of \$5,700 x 10^6: 130 = \$43.85 millions; approximately the same as the Akron of 6.50 x 10^6 ft^3 (.184 x $10^6 m^3$) volume should have cost in 1974, by simply inflating the 1931 price with no consideration to the cost increase due to the technology advancements.

Very approximate operating cost per airship per flight hour has been estimated at \$3,519, broken down as follows:

	$/FH
Capital cost, amortization and interest	639
Crew	164
Fluid, JP-5 for propulsion and steam for return buoyant fluid	1,313
Maintenance, spares and amortization and interest for base facilities	1,083
Profit 10%	320

The operating cost for a fleet of 130 LTA vehicles will amount to \$457,470 per hour, 2.2 times higher than the pumping cost (see 4.5.2.1, Baseline).

4.5.2.6 Summary

The comparison between the planned Alaska natural gas pipeline and a fleet of airships to supply the same capacity is summarized in Table 4-IV.

Table 4–IV. Transport of Natural Gas. LTA Vehicle vs Pipeline

BASELINE: PLANNED ALASKA NATURAL GAS PIPELINE					
LENGTH MI	CAPACITY N FT^3/DAY	FIRST INVESTMENT COST $	PUMPING COST $/HOUR		
2,600	5,479.5 X 10^6	5,700 X 10^6	207,764		

LTA VEHICLE					
VOLUME FT^3	CRUISE SPEED KT	REQUIRED NUMBER OF LTAs TO MATCH CAPACITY (AVAILABILITY 85%)	ALLOWABLE COMPETITIVE FIRST INVEST-MENT COST PER LTA $	OPERATING COST FOR 130 LTAs $/HOUR	RATIO OPERATING COST LTA: PIPELINE
100 x 10^6	100	130	43.85 x 10^6	457,470	2.2

CONVERSION FACTORS: 1 NM = 1.852 KM, 1 FT^3= 0.0283 M^3, 1 KT = 0.514 M/S

4.5.3 A Comparison With An LNG System

4.5.3.1 Baseline

The baseline for comparison of the performance of an airship fleet is a hypothetical LNG import project, analyzed by U.S. Federal Power Commission.[53] This case is based upon actual data, adjusted to 1975.

- Delivered capacity by LNG tanker — 479×10^6 N ft^3/day (13.6×10^6 N m^3/day)
- Round-Trip — 7000 NM (12,964 km)
- Investments for LNG System — $\$556 \times 10^6$
  - Liquefaction Plant — $\$221 \times 10^6$
  - LNG Tankers — $\$263 \times 10^6$
  - Receiving Terminal — $\$72 \times 10^6$

4.5.3.2 Loading and Unloading

The same assumptions as in 4.5.2.2 apply. Loading and unloading time will each be 1.11 hours for 70.185×10^6 N ft^3 (1.988×10^6 N m^3) (See discussion of delivered volume in Paragraph 4.5.3.4).

4.5.3.3 Mission Profile

Loading and unloading times have been established above. The mission profile including time will be as shown in Figure 4-10.

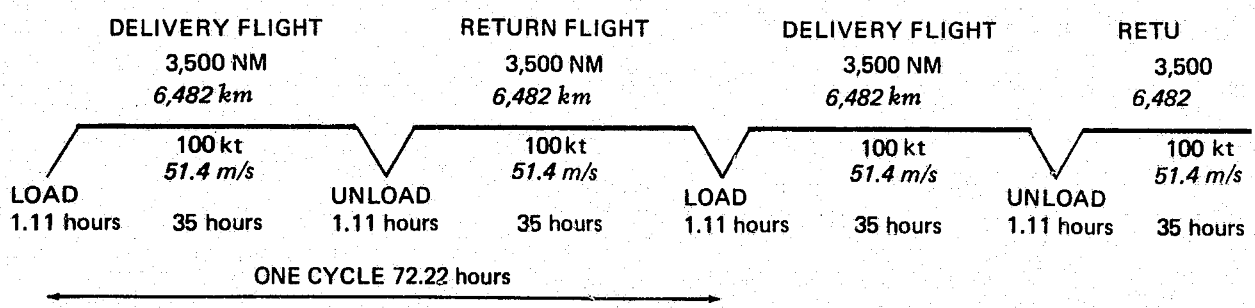


Figure 4—10. Natural Gas Transport Mission Profile (Lng Case)

The delivery flight is a low altitude flight and the return flight a high altitude flight. The pressure altitude of the airship on the return leg is about 13,500 ft (4,115 m). The sea level gas volume being 66% of volume capacity.

4.5.3.4 LTA Vehicle Configuration and Required Quantity

The LTA vehicle configuration will be as described in Paragraph 4.5.2.4 including the availability factor of .85. The payload, however, must be reduced as can be seen from Figure 4-6. The required fuel load for the distance of 3,500 NM (6,482 km) plus 10% reserve increases the mission weight beyond the lifting capability of a fully filled airship. Consequently, a buoyant fluid of higher specific lift has to be added. Steam was selected on the grounds previously discussed. The required volume of steam will reduce the natural gas volume to 70.185×10^6 N ft^3 (1.988×10^6 Nm^3)

To match the capacity of the LNG tankers in Paragraph 4.5.3.1 Baseline, a quantity of 24 airships will be required.

4.5.3.5 Costs

It is assumed that the first investment cost for the fleet of LTA vehicles cannot exceed the investment for LNG liquefaction plant, LNG tankers, and receiving terminal $556 million. (See Paragraph 4.5.3.1 Baseline) By doing that, the cost of required terminals for the airship is neglected. In other words, the assumption made is in favor of the LTA system. If all costs connected with the LTA system should be considered, the allowable competitive airship unit cost should be still lower.

Consequently, with all the optimistic assumptions, the allowable unit cost of an airship for the described mission is $23.2 millions. Such a low unit cost is unachievable.

The operating costs, very approximate and developed in the same manner as for the "Alaska Pipeline Case", Paragraph 4.5.2.5, are $80,184 per flight hour for the airship fleet of 24 vehicles. With these costs and a wellhead price of 70¢ per 1,000 N ft^3 ($2.47 per 100 Nm^3 (in U.S.A. end of 1974) the U.S. port price of natural gas imported by airship from a source 3,500 NM (6.432 km) away, will be $5.25 per 1,000 N ft^3 ($18.54 per 100 Nm^3);4 times higher than the average price paid in 1973 for LNG imported by tankers.[53]

4.5.3.6 Summary

The comparison between an LNG import case and an airship system for the same amount of natural gas in gaseous state is summarized in Table 4-V.

Table 4–V. Transport of Natural Gas. LTA Vehicle vs LNG Tanker

<table>
<tr><td colspan="7">BASELINE: NATIONAL GAS SURVEY HYPOTHETICAL LNG IMPORT PROJECT</td></tr>
<tr><td colspan="2">ONE-WAY DISTANCE NM</td><td>DELIVERED CAPACITY N FT^3/DAY</td><td>FIRST INVESTMENT COST, LNG SYSTEM $</td><td></td><td>COST OF NG AT U.S. PORT $/10^3 N FT^3 $/10^2 Nm^3</td><td></td></tr>
<tr><td colspan="2">3,500</td><td>479 X 10^6</td><td>556 X 10^6</td><td></td><td>1.27</td><td></td></tr>
<tr><td colspan="7">LTA VEHICLE</td></tr>
<tr><td>VOLUME FT^3</td><td>CRUISE SPEED KT</td><td>REQUIRED NUMBER OF LTAs TO MATCH CAPACITY (AVAILABILITY 85%)</td><td>ALLOWABLE COMPETITIVE FIRST INVEST-MENT COST PER LTA $</td><td>OPERATING COST FOR 24 LTAs $/HOUR</td><td>COST OF NG AT U.S. PORT $/10^3 N FT^3</td><td>RATIO OF COST LTA: LNG</td></tr>
<tr><td>100 X 10^6</td><td>100</td><td>24</td><td>23.2 X 10^6</td><td>80,184</td><td>5.25</td><td>4.13</td></tr>
</table>

CONVERSION FACTORS: 1 MI = 1.609 KM, 1 FT^3 = 0.0283 M^3, 1 KT = 0.514 M/S

4.6 Potential Passenger Service Market

The main source for personal trips data in the U.S. is the National Travel Survey 1972 published by the Bureau of Census.[30] Tables 4-VI and 4-VII are excerpts from this document giving the person-trips in millions by origin region and destination region. Much detail is contained in the survey of the distribution of personal trips with mode of travel and socio-economical categories. However, personal trips between given city-pairs is not included.

Table 4–VI. Travel by Origin Region

(In millions. Excludes trips with destinations outside the United States)

Region of origin	1972 Population estimates[1] (millions)	Trips (millions)	Trips per capita	Person-trips (millions)	Person-miles (billions)	Person-nights (millions)
New England	12.0	12.6	1.05	23.6	17.5	81.6
New York-New Jersey	25.7	18.4	.72	33.9	34.4	155.7
Mid-Atlantic	23.6	23.3	.99	44.0	33.5	158.7
South	38.2	39.3	1.03	73.0	59.5	253.0
North Central	47.6	54.5	1.14	109.7	89.7	408.4
Northwest	7.4	10.7	1.45	21.0	18.5	70.6
Southwest	24.0	32.0	1.33	65.8	51.6	202.2
Pacific	28.0	36.1	1.29	69.1	64.9	240.9

[1]July 1972 population estimates, Current Population Survey, Bureau of the Census, "Estimates of Populations of States: July 1, 1971 and 1972", Series P-25, No. 488.

Table 4-VII. Travel by Destination Region

(In millions)

Region of destination	1972 Population estimates[1] (millions)	Trips (millions)	Trips per capita (of origin)	Person-trips (millions)	Person-miles (billions)	Person-nights (millions)
New England	12.0	12.5	1.04	25.0	16.8	97.0
New York-New Jersey	25.7	15.8	.61	28.8	20.8	101.1
Mid-Atlantic	23.6	23.2	.98	43.2	27.9	137.6
South	38.2	46.5	1.22	88.2	85.9	385.2
North Central	47.6	47.1	1.00	94.0	59.0	278.7
Northwest	7.4	11.5	1.55	22.5	22.7	91.6
Southwest	24.0	32.5	1.35	66.8	53.5	207.0
Pacific	28.0	37.8	1.35	71.5	83.0	272.1
Outside United States	(X)	10.1	(X)	18.4	(X)	211.7

[1]July 1972 population estimates, Current Population Survey, Bureau of the Census, "Estimates of Populations of States: July 1, 1971 and 1972", Series P-25, No. 488.

The North East Corridor Study has data for some city pairs for 1966.[32] A study done for the Assistant Secretary of the U.S. Department of Transportation by the Mitre Corporation investigated the potential market for an Improved Passenger Train (IPT) and a Tracked Levitation Vehicle (TLV) and has relevant data on person trips between city pairs projected to the years 1985 and 1995.[31] The study also includes a Mode Split Model, which relates journey time, cost and 'acceptance' factor to market share for a particular mode. This data has been used in developing a passenger travel market potential for an LTA vehicle in 1985.

Table 4-VIII is taken from the study and shows the total person trips between given city pairs. San Francisco to Los Angeles and Los Angeles to San Diego was selected as the route to investigate for the application of the LTA vehicle because the annual passenger miles were high and approximately the same, the segments could be made over water and would require no high altitude operation, the climate is relatively mild and a sensitivity study had been done by Mitre into the Los Angeles-San Diego segment of fare level, speed and the effect of a 50% and a 200% increase in fuel prices.

Table 4–VIII. Estimated Total Travel Demand by Corridor, City-Pair, and Year

Corridor	City-Pair	Year 1970	Year 1975	Year 1985	Year 1995
Chicago-Detroit (292 route miles)	Chicago-Detroit	1,386,000	1,566,180	2,037,420	2,578,000
	Chicago-South Bend	955,000	1,079,150	1,403,850	1,776,300
	Chicago-Toledo	332,000	375,000	488,000	617,500
	South Bend-Toledo	31,500	35,600	46,300	58,600
	South Bend-Detroit	93,000	105,090	136,700	173,000
	Toledo-Detroit	2,672,000	3,019,360	3,927,800	4,970,000
		5,469,500	6,180,380	8,040,070	10,173,400
Seattle-Portland (186 Route miles)	Seattle-Portland	2,612,600	3,108,300	4,440,400	5,772,500
California (683 route miles)	Sacramento-San Francisco	5,087,600	6,206,870	8,700,000	11,500,000
	Sacramento-Stockton	1,289,600	1,573,300	2,205,200	2,915,000
	Sacramento-Fresno	264,600	325,468	468,342	630,000
	Sacramento-Bakersfield	51,700	63,591	91,500	123,000
	Sacramento-Los Angeles	1,374,220	1,690,290	2,432,400	3,270,000
	San Francisco-Stockton	3,023,550	3,688,700	5,170,300	6,833,000
	San Francisco-Fresno	607,800	662,500	1,075,800	1,446,600
	San Francisco-Bakersfield	205,200	252,400	363,200	448,400
	San Francisco-Los Angeles	8,200,000	10,086,000	14,500,000	19,516,000
	Stockton-Fresno	152,750	187,882	270,400	363,545
	Stockton-Bakersfield	36,680	32,816	47,200	63,500
	Stockton-Los Angeles	590,500	726,300	1,045,200	1,405,400
	Fresno-Bakersfield	512,700	630,600	907,500	1,220,200
	Fresno-Los Angeles	1,042,650	1,282,500	1,845,500	2,481,500
	Fresno-San Diego	54,400	66,900	96,300	129,500
	Bakersfield-Los Angeles	3,252,400	4,000,500	5,756,700	7,740,700
	Bakersfield-San Diego	68,250	83,950	120,800	162,400
	Los Angeles-San Diego	27,000,000	33,750,000	49,780,000	68,040,000
		52,804,600	65,310,567	94,776,342	128,328,745

4.6.1 San Francisco - Los Angeles

Distance = 320 NM (593 km)

Estimated total travel demand, 1985 = 14.5 million person trips

Market Share for 95 m.p.h. (83 kt) (42.5 m/s) Improved Passenger Train on the Los Angeles to San Diego leg = 9.5% at 6 cents a passenger mile[31]

Using the Model Split Model equation in page A-9 of Reference 31, the market share for a 100 knots (51.4 m/s) airship was determined as 12.6% at 6 cents a passenger mile. Table 4-IX details the market share for higher fare levels and the required direct operating costs in cents per seat mile that the airship would have to achieve.

Table 4–IX. Market Share at Higher Fare Levels and Competitive D.O.C., San Francisco-Los Angeles

Fare Ratio	1.0	1.4	1.8	2.2
Fare (¢/px.mi)	6.0	8.4	10.8	13.2
Market Share (%)	12.6	9.4	7.6	6.4
Passengers per annum (x 10^6)	1.83	1.36	1.10	0.93
Px-miles per annum (x 10^6)	651.48	484.16	391.60	330.37
Px per day (One way)	2542	1889	1528	1292
Number of Px per Airship (1)	.363	270	218	184
Load Factor (%)	72.6	54.0	43.6	36.9
Annual Revenue ($ x 10^6)	38.09	40.67	42.29	43.60
Less 5% (2)	36.18	38.64	40.17	41.43
Less Indirect Costs (3)	16.63	24.11	28.42	31.52
D.O.C. $/hour (4)	1045	1515	1786	1984
D.O.C. ¢/seat mile (incl. 5% profit)	1.8	2.6	3.1	3.3
With No 5% Profit	2.0	2.9	3.3	3.5

To obtain International System Units:
¢/mi: 1.609 = ¢/km

The tabulation above assumes a 500 seat airship

(1) Assumes 7 flights a day each way

(2) Reserve or profit

(3) Based on $0.03 per passenger mile[32]

(4) Total annual fleet flying hours is 15,885 hours determined as follows: -

One way trip flying time = 3.09 hours

Number of trips per day, each way = 14

Total annual revenue flying hours = 14 x 3.09 x 360

= 15,574

Plus 2% non revenue flying 15,885 hours.

For 5 airships, this would require an annual utilization to which the direct operating cost should be related. However, the exact number of airships would be determined by the schedule and what reserve is carried.

4.6.2 Los Angeles to San Diego

Distance = 91 NM (169 km)

Estimated total travel demand 1985

= 49.68 million person trips

Using the Mode Split Model equation referred to in the previous section, Table 4-X details the market share with varying fare levels and the required direct operating costs of the airship.

Table 4—X. Market Share at Higher Fare Levels and Competitive D.O.C., Los Angeles-San Diego

Fare Ratio	1.0	1.4	1.8	2.2
Fare (¢/px mi)	6.0	8.4	10.8	13.2
Market Share (%)	10.8	8.1	6.5	5.5
Passengers per annum $\times 10^6$	5.36	4.02	3.23	2.73
Px - miles $\times 10^6$	578.88	434.16	348.84	294.84
Px per day (One way)	7444	5583	4486	792
No. of Px per Airship (1)	465	349	280	237
Load Factor (%)	98.0	69.8	56.0	47.4
Annual Revenue $ $\times 10^6$	34.73	36.47	37.67	38.92
Less 5% (2)	32.99	34.65	35.79	36.97

Less Indirect (3)	15.62	21.63	25.32	28.12
D.O.C. $/hour (4)	1477	2045	2394	2659
D.O.C. ¢/seat mile (incl. 5% profit)	2.5	3.4	4.0	4.4
With no 5% profit	2.7	3.7	4.3	4.7

To obtain International System Units: ¢/mi: 1.609 = ¢/km

This assumes a 500 seat airship; it could be that because this is a shorter distance than the San Francisco to Los Angeles leg, less fuel would be required and the seat capacity could be increased to make the load factor at the lower fares more acceptable.

(1) Assumes 16 flights a day each way
(2) Reserve or profit
(3) Based on $0.03 per passenger mile
(4) Total annual fleet flying hours is 10,575 hours determined as follows:

One trip flying time = 0.9 hours

Number of trips per day = 32

Annual Revenue flying hours

= 32 x 0.9 x 360

= 10,368 hours

Plus 2% non-revenue flying

= 10,575 hours

For a 3 airship fleet this would represent 3525 hours a year.

Reference 31 estimates the effect on market share if fuel costs were raised 50% to 200% in this time period, i.e., by 1985. The effect on trip costs for each mode is different, trip costs for auto go up directly as fuel costs since the 'perceived' costs of auto travel are dominated by fuel costs. It is estimated that the effect on the airship would lie somewhere between that of the bus and the Tracked Levitation Vehicle (TLV) since the energy per seat mile of the airship is estimated to be somewhere between these two.

4.6.3 Effect of Increase in Fuel Costs

The effect of fuel costs on market share for the TLV is detailed in Reference 31. Tables 4-XI and 4-XII illustrate the effect of a 50% increase on airship share and direct operating costs for the two segments, San Francisco to Los Angeles and Los Angeles to San Diego.

Table 4–XI. Market Share and D.O.C. at 50% Increase in Fuel Costs, San Francisco-Los Angeles

Fare (¢/px mi)	6.0	8.4	10.8	13.2
Market Share (%)	15.4	11.5	9.3	7.8
DOC ($/hr)	1160	1861	2196	2415
DOC (¢/seat mile)	1.9	3.1	3.7	4.0
With no 5% profit	2.5	3.4	3.9	4.3

Table 4–XII. Market Share and D.O.C. at 50% Increase in Fuel Costs, Los Angeles-San Diego

Fare (¢/px mi)	6.0	8.4	10.8	13.2
Market Share (%)	13.2	9.9	8.0	6.7
DOC ($/hr)	1809	2502	2936	3254
DOC (¢/seat mile)	3.0	4.2	4.9	5.4
With no 5% profit	3.3	4.5	5.3	5.8

An increase of 200% in fuel costs will affect the market share and D.O.C. as shown in Tables 4-XIII and 4-XIV.

Table 4–XIII. Market Share and D.O.C. at 200% Increase in Fuel Costs, San Francisco-Los Angeles

Fare (¢/px mi)	6.0	8.4	10.8	13.3
Market Share (%)	18.9	14.1	11.4	9.6
D.O.C. ($/hour)	1571	2276	2684	2975
D.O.C. (¢/seat mile)	2.6	3.8	4.5	5.0
With no 5% profit	2.9	4.1	4.8	5.3

Table 4–XIV. Market Share and D.O.C. at 200% Increase in Fuel Costs, Los Angeles-San Diego

Fare (¢/px mi.)	6.0	8.4	10.8	13.2
Market Share (%)	16.2	12.2	9.7	8.2
D.O.C. ($/hour)	1970	2726	3192	3546
D.O.C. (¢/seat mile)	3.3	4.5	5.3	5.9
With no 5% profit	3.6	4.9	5.7	6.3

To obtain International System Units: ¢/mi: 1.609 = ¢/km

It should be noted that the airship is in a very competitive air travel market in California. Pacific Southwest Airlines has a fare level of around 7 to 8 cents a seat mile; in other areas the market share could probably be achieved at higher fare levels.

An investigation was made into the Seattle to Portland travel market but the passenger miles generated by this city pair is some 88% less than that generated by San Francisco to Los Angeles and Los Angeles to San Diego and results in a very low frequency schedule and hence low annual utilization for a 500 seat airship to maintain reasonable load factors (30% to 60%). However, a 100 kt (51.4 m/s) airship could obtain 19.3% of this market at a fare level of 9.5 cents a passenger mile to 9.8% at a fare level of 20.9 cents a passenger mile.

On the assumption that the airship could take 25 tons of freight and had a 250 seat passenger capacity and the freight revenue varied from 15 cents a ton-mile to 33 cents a ton-mile. with corresponding freight load factors of 80% decreasing to 30%. The airship would require a direct operating cost of from $1470 per hour to $1880 per hour with an annual utilization of 2400 hours a year for three airships. This mixture of freight and passengers requires more detail investigation of the advantages and use of the airship.

Table 4-XV summarizes the results of the San Francisco to Los Angeles and Los Angeles to San Diego investigation.

Table 4–XV. Passenger Traffic Summary Market Share and D.O.C.

Fare (¢/p.m.)		6.0		8.4		10.8		13.2
Route	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Market Share (%)								
No Fuel Increase	12.6	10.8	9.4	8.1	7.6	6.5	6.4	5.5
50% Fuel Increase	15.4	13.2	11.5	9.9	9.3	8.0	7.8	6.7
200% Fuel Increase	18.9	16.2	14.1	12.2	11.4	9.7	9.6	8.2
D.O.C. ($/hour)								
No Fuel Increase	1045	1477	1515	2045	1786	2394	1984	2659
50% Fuel Increase	1160	1809	1861	2502	2196	2936	2415	3254
200% Fuel Increase	1571	1970	2276	2726	2684	3192	2975	3546
D.O.C. (¢/seat-mile)								
No Fuel Increase	1.8	2.5	2.6	3.4	3.1	4.0	3.3	4.4
50% Fuel Increase	1.9	3.0	3.1	4.2	3.7	4.9	4.0	5.4
200% Fuel Increase	2.6	3.3	3.8	4.5	4.5	5.3	5.0	5.9

(1) San Francisco-Los Angeles (2) Los Angeles-San Diego

To obtain International System Units: ¢/mi: 1.609 = ¢/km

This analysis has indicated that in the freight transport and passenger travel markets in the United States, there are segments that have potential for an LTA vehicle with a 50 ton/500 passenger payload capacity, a cruise speed of 100 kt (51.4 m/s) and a VTOL capability or, at a minimum, short take-off and vertical landing capability. To penetrate these markets, the LTA vehicle should have a direct operating cost of between \$500 to \$800 an hour in the freight market and between \$110 and \$2700 an hour in the passenger travel market with utilizations between 2000 hours and 4000 hours a year.

4.7 Commuter Traffic Analysis

It has been suggested that commuter traffic may be a viable mission for an LTA vehicle, especially if a rail network does not exist and must be constructed.

The scope of this phase of the conceptual study as well as time did not allow a complete trade-off study between a railborne and airborne commuter system. However, an analysis of the possible performance of an aerial commuter line has been done and compared with the performance of Boeing Vertol railroad car SOAC (State-of-the-Art Car), equivalent numbers of vehicles established, and the approximate price of the SOAC given.

The airship concept has assumed a 200 passenger Helipsoid airship with a buoyancy ratio of 67%. Approximate volume 2×10^6 ft^3 (57×10^3 m^3). The flight altitude is 330 ft (100 m) and the vehicle follows a fixed route lane guided by ground-located electronic beams sending signals to the autopilot in the airship. Each "station" consists of a platform at an elevation of 66 ft. (20 m). Figure 4-11 shows an artist's concept of the visualized commuter line.

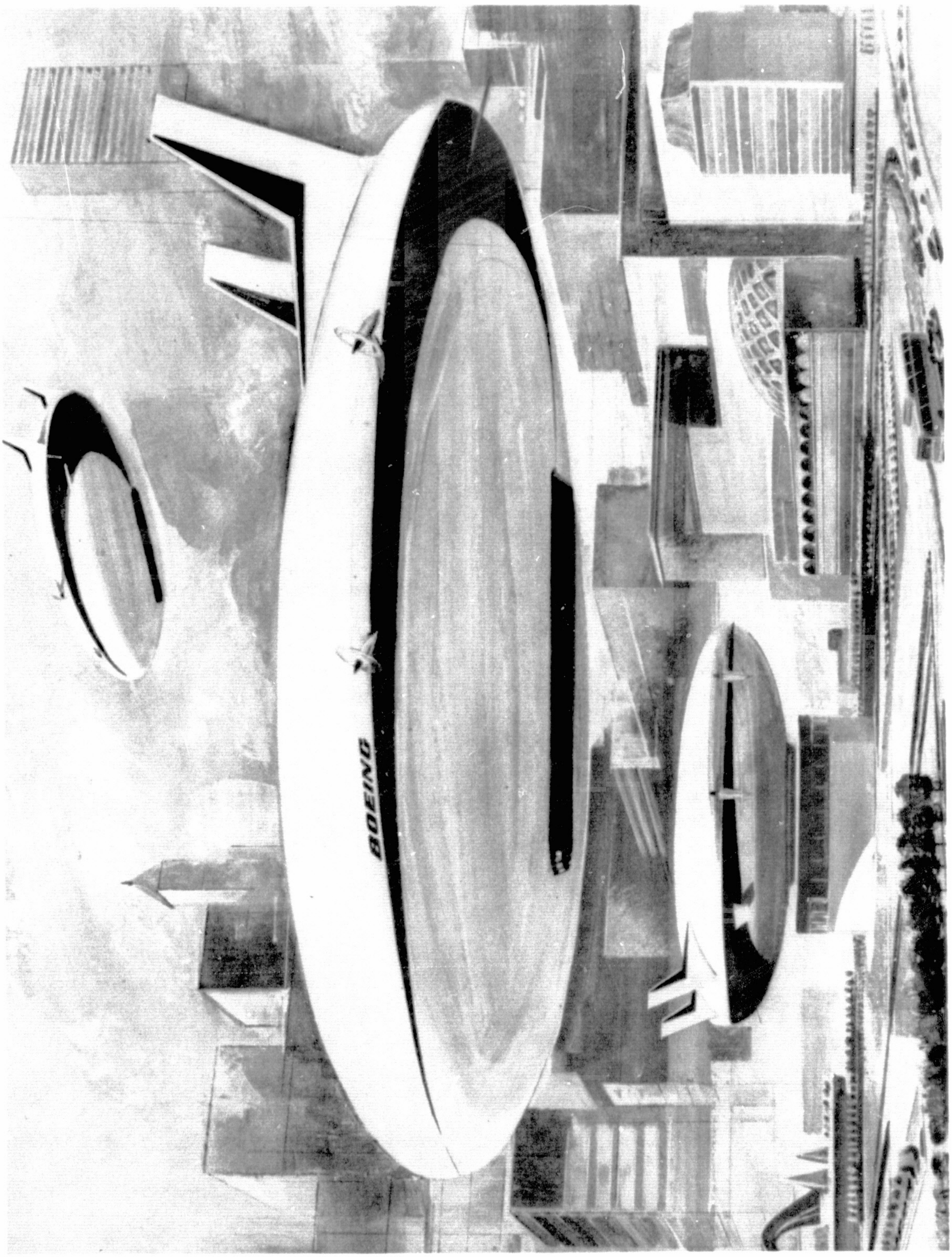


Figure 4–11. Airship Commuter Line

ORIGINAL PAGE IS
OF POOR QUALITY

To assess the relative merits of the airship as an alternative transit vehicle, route performance was evaluated for a 200 passenger airship and compared with that of the State-of-the-Art Car (SOAC) which as it turns out has an almost identical weight for the vehicle less the passenger load. The urban transit route selected for this comparison is a low density route which was initially set up for the study of the advanced concept trains (ACT). This route possesses station spacing distances that vary from 0.5 to 1.8 miles (800 to 2,900 m). Peak passengers demand is 10,000 passengers per hour. A high density route which has station spacing distances as low as 0.25 miles (400 m) and passenger demand up to 60,000 passengers per hour was not evaluated as it was thought to be too severe an application for the airship. The route performance analysis served to establish vehicle block or schedule speed which together with known route and vehicle parameters (i.e. passenger demand, passenger capacity per car and total route distance) could be used to determine fleet requirements.

The results of the route performance analysis are illustrated in Figure 4-12 which presents the average cruise speed, block speed and block time as a function of maximum cruise speed. The SOAC vehicle was evaluated at maximum cruise speeds of 80 mph (36 m/s) and 68 mph (85% max.). The 80 mph (36 m/s) maximum cruise speed represents the limit speed for the rail transit route. The airship was evaluated at maximum cruise speeds of 80 (36 m/s) and 100 mph (45 m/s). Airship acceleration and deceleration capability was established based on data on positive and negative thrust capability for the airship propulsion system.

The station stopping dwell is 20 seconds for the SOAC, whereas it is 65 seconds for the airship. The airship dwell includes 30 seconds for descent from the 330 ft (100 m) cruise altitude 20 seconds for passenger loading/unloading and 15 seconds for climb to cruise altitude.

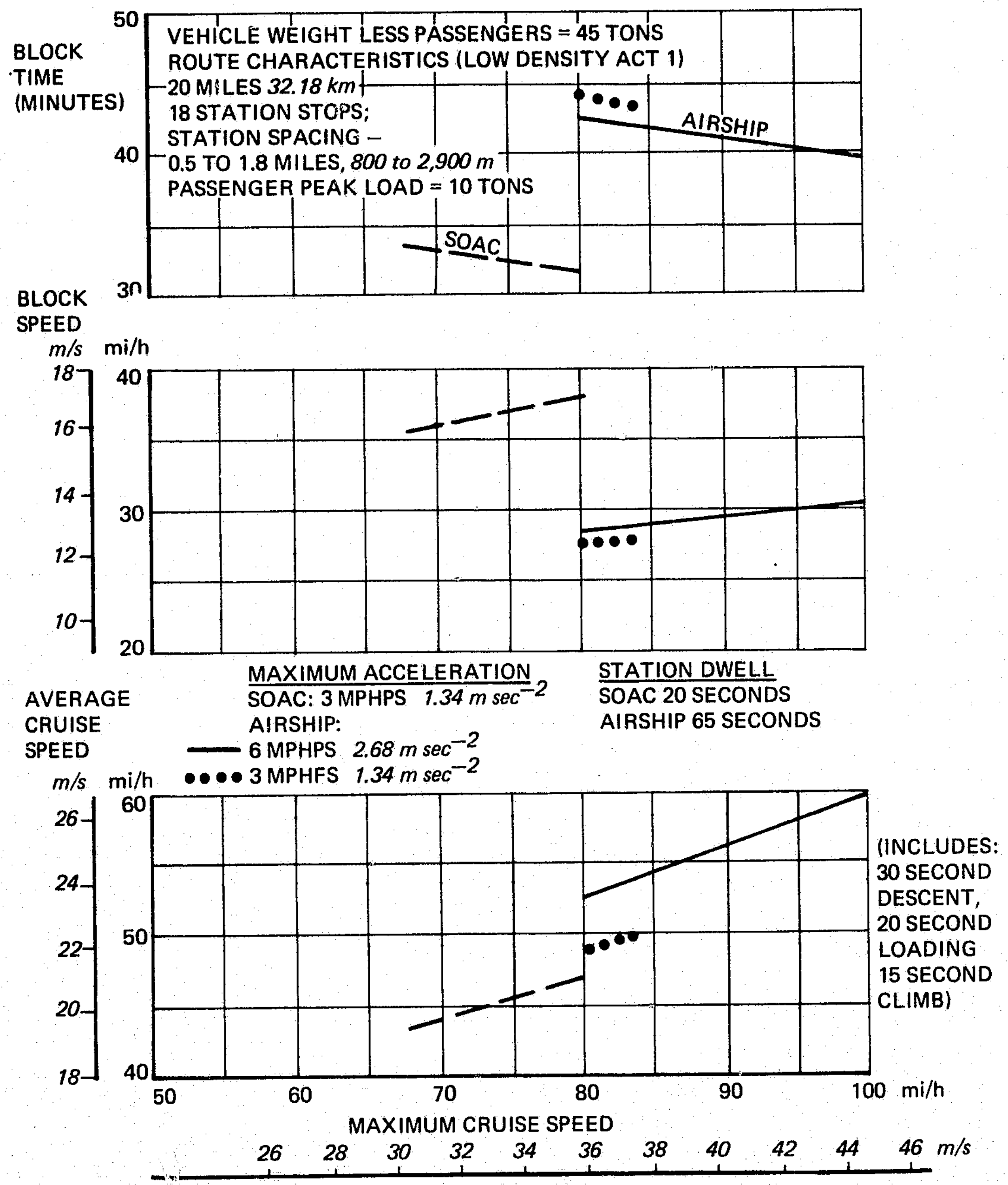


Figure 4–12. Airship Urban Commuter Capability

As shown in Figure 4-12, although the SOAC vehicle is constrained to a lower maximum cruise speed, it achieves a higher block speed or a lower block time than the airship to traverse the 20 mile (32.18 km) "low density" route. Increasing the maximum allowable acceleration from 3 mphs (1.34 $m \cdot sec^{-2}$) which is the value for the SOAC, to 6 mphps (2.68 $m \cdot sec^{-2}$) improves the average cruise speed of the airship but does not materially effect block time or block speed. The block speed accounts for dwell time which for the airship is considerably higher than that for the train. This is due to the fact that the airship takes time to climb to and descend from cruise altitude. This increment in time which is repeated at every station stop is not offset by either increased maximum cruise speed or vehicle acceleration.

There is a practical limit to the maximum cruise speed attained between stations that depends on the acceleration, and deceleration capability and the distance between stations. This means that even though a vehicle may have a high potential cruise speed, it may not always be achievable because the point is reached where further increases in cruise speed will cause the vehicle to stop at some point beyond the station. Further, a speed profile which consists solely of acceleration to peak speed and then immediate deceleration to stop at the station with no constant cruise segment between stations does not produce a comfortable ride. This must be considered as it affects passenger appeal and demand.

The passenger loading and/or unloading time of 20 seconds, although used in the analysis for the airship, appears inadequate in consideration of airworthiness regulations which will probably require airship passengers to fasten seat belts as all airship passengers will have to be seated and secured. Some way to assure compliance with this requirement will have to be found. Possible alternatives are an "ignition" type seat belt - interlock or a steward service.

To satisfy the traffic volume of 10,000 passengers per hour for the low density profile requires 66 airship vehicles with a maximum cruise speed of 100 mph (45 m/s) or 56 SOAC vehicles with a maximum cruise speed of 68 mph (30 m/s). This assumes both vehicles have capacity for 200 passengers.

In light of the above analysis, required size and quantity of airships and considering that the cost of a SOAC is approximately 1975 $400,000, the preliminary conclusion must be that the airship does not appear to be a competitive alternative in the commuter traffic system. For a more definite conclusion, a separate analysis will be required addressing the full complexity of railbound system installation, airborne system installation, airship development, certification, production, flight rules, all-weather operations, effect of high-rise station platforms at cruise level to eliminate ascent/descent time, etc.

4.8 Surveillance Missions

Particular surveillance missions that have been defined for potential application of an LTA vehicle are U.S. Coast Guard missions, the police traffic and crime control tasks.

4.8.1 U.S. Coast Guard Potential Missions

The Coast Guard has five basic missions which describe most of their operational responsibilities. They are: (1) Search and Rescue (SAR); (2) Aids to Navigation (ATN); (3) Enforcement of Laws and Treaties (ELT); (4) Marine and Environmental Protection (MEP); and (5) Polar Operations (PO). Each one of these five missions has some application that could be satisfied effectively by a lighter-than-air device. The objective of this summary is to specify two, or, at the most, three missions and payload characteristics which would represent the summary of these activities.

There are similarities between the various missions. The ATN and MEP missions are predominantly heavy lift missions with relatively long-range requirements. Heavy lift in this case is upwards of 20 to 30 tons. A maximum ATN patrol could use 200 tons disposable load.

The search part of SAR, the ELT missions, and to some extent Polar Operations, is mainly surveillance type of activities. This means carrying electronic devices, maintaining a fairly long time on patrol, and some close station-keeping in moderate winds. Rescue and some aspects of the ELT missions require the ability to transfer crews, boarding parties, or rescue units from the vehicle which brought them to the area, to the vessel, raft or the surface, in some cases, in rather unfriendly seas.

Therefore, the following mission definitions have been established:

4.8.1.1 Mission 1 - Surveillance

To satisfy this mission the LTA vehicle will be required to possess the following general capabilities.

a. Possess precise maneuverability and have the ability to hold a position in 30+ kt (15.4 m/s) of wind within ± 5 ft (1.5 m).

b. Operate independently; i.e., not require improved landing facilities or close support from surface craft or other aircraft (this is not to mean it will not be expected to work with other units when the need arises).

c. Be able to conduct unrestricted operations with respect to wind and rain, etc., for enroute transit purposes and to possess a capability of self-preservation under severe operational conditions (hurricane force).

d. With the establishment of the 200 NM (370.4 km) economic zone, the Coast Guard will have the responsibility of patrolling an area having a perimeter of approximately 8700 NM (16,112 km) and including over 2×10^6 NM^2 (5.18×10^6 km). In order to effectively patrol this area, the LTA vehicle should have the following capabilities:

1. Speed -- 0-150+kt (0-77 m/s) with economical cruise at 25-30 kt (12.9 - 15.4 m/s).

2. Endurance -- 10-14 days (or trade-off quick response replacement) but contact has to be continuous on the vessel under surveillance.

3. Load -- Ability to carry full crew, observers, and a sensor package to collect and record data (round the clock crew as required by vehicle, sensor = 1500 lb (680 kg)).

4. Transfer personnel -- The LTA should be able to transfer crews and deploy and retrieve boarding parties (8 men). This implies the capability to hover with precise controllability within 10 ft (3 m) - transfers limited to 35 kt (18 m/s).

5. Weather -- All-weather capability from tropical to arctic conditions with wind tolerance to approximately 75 kt (38.6 m/s).

4.8.1.2 <u>Mission 2 - Heavy Utility</u>

This mission includes aspects of rescue, ATN, MEP, and special services:

The a., b., and c. capabilities in 4.8.1.1 apply in this case as well.

The capability d. has a broad trade-off between range and maximum heavy lift. The minimum lift capability is 20 tons to be airlifted 2000 NM (3,704 km) in 10 hours. The maximum heavy lift might be 200 tons to be transported 300 NM (555.6 km)

a. Speed at maximum load -- not less than 30 kt (15.4 m/s).

b. Endurance (trade-off with load).

c. Transfer personnel to surface.

d. Deployment of load -- ability to stay under control within winch capability when load is transferred.

e. Weather -- generally good - winds to 30-35 kt (15.4-18 m/s).

4.8.1.3 Mission 3 - Special

Remotely-piloted LTA vehicles: A potential exists to utilize smaller remotely piloted sensor-equipped vehicles to extend the coverage of a surface vessel. The vehicles would require moderate endurance and must have suitable ground-handling characteristics for deployment aboard ship.

If a water landing is possible, it would be beneficial for recovering survivors and search targets - either by the basic vehicle or by RPV.

Mission profiles have been developed based upon the three missions above for sizing by computer. This is discussed in Paragraph 6.

4.8.2 Police Potential Use

There are over 100 police departments using about 300 helicopters in the U.S. today. These are small helicopters with payloads from 500 to 1000 lb (227-454 kg),endurances of 1-2 hours, cruise speeds around 100 kt (51.4 m/s) and direct operating costs of from $60 to $130 an hour. Projections to the year 1980 indicate that the police helicopter fleet could be as high as 600. Payload and speed are adequate for the missions in which they are used, however, high operations costs and in some missions low endurance are considered limiting factors.

At maximum endurance speeds around 25 to 35 kt (13-18 m/s) the fuel consumption of these helicopters is of the order of 90 lb/hr (40.8 kg/hr). An LTA vehicle that could equal or be less than this with lower fuel consumption in a hover at zero wind condition and direct operating cost less than the helicopter could be expected to capture a part of this market. However, it is unlikely that ownership cost and direct operating cost can challenge the corresponding helicopter costs. It should be noted that the existing police helicopters are only a small portion of the total number of helicopters manufactured of this size.

The possibilities for very long endurance and remotely piloted airship with surveillance sensors installed could be attractive for certain missions.[25] Such a requirement does not presently exist. It has to be developed as well as acceptability of having an unmanned LTA vehicle loitering over populated areas.

Conclusions are that the "police LTA market" will not revive the airship in the near future.

4.9 Military Potential Missions

An assessment of the feasibility of a modern airship should not be complete without consideration given to military missions. The airship is nothing else than a tool or platform for carrying equipment and loads so that contemplated missions can be accomplished; commercial or military - the same LTA vehicle platform could be used.

4.9.1 U.S. Navy Missions

Two promising missions for an LTA vehicle are emerging in the airship study being performed by the U.S. Naval Air Development Center (NADC). Although the mission information is still in the preliminary stage, it is considered appropriate and beneficial to briefly discuss those missions and the requirements. The discussion is based upon information supplied by NADC.

The two potential missions are related primarily to ASW and surveillance. The first mission - long endurance ASW mission - will require a large LTA vehicle capable of sustained, independent operations for long periods of time.

The second mission - AEW/ASW/SS mission - reflects a much smaller LTA vehicle which could probably also perform many of the less demanding LTA missions and which would also have the unique capability to be supported at sea by surface ships for the purposes of increasing its basic payload and/or mission duration. This second mission is primarily directed towards Sea Control and the defense of surface forces.

The long endurance ASW airship will be self sufficient and capable of independent operations from land bases for periods requiring multiple crews and hotel facilities. It will be supplementary to both surface and aircraft resources, thus relieving the burden on these forces in situations where economics or threat levels make the long endurance LTA attractive. In simplistic terms, it is intended to fill the gap between relatively slow-speed, long endurance, large payload surface ships and high-speed, short endurance, small payload aircraft. Although the long endurance ASW airship will be self-sufficient, it will also be able, by virtue of its low-speed capability, to use ships for replenishment of fuel and other consumables when operating in conjunction with surface forces.

Endurance on station rather than reaction time is emphasized. It is expected that Remotely Piloted Vehicles (RPVs) or manned aircraft, carried onboard, will supply functions requiring

high speed, threat exposure, or high altitude.

Preliminary characteristics for a fully buoyant (preferred for the hover requirement) airship for a long endurance ASW mission are:

Volume: 6×10^6 ft^3 (170×10^3 m^3)

Cruise Speed: 120 kt (62 m/s)

Altitude: 10,000 ft (3,050 m)

Mission Duration: 10 days

The AEW/ASW/SS airship would be landbased, but will be dependent on ship support for long endurance missions. Ship support will consist of replenishment of consumables, crew changeout, spares, and avionics support. The LTA will rendezvous with support ships for turnaround approximately every six to eight hours. Total mission duration of 10 to 30 days are desired. Ferry capability from support ship to home base of about 2,500 NM (4,630 km) is desired.

Preliminary characteristics for the AEW/ASW/SS airship are:

Volume: 1.2×10^6 ft^3 (34×10^3 m^3)

Cruise Speed: 100 kt (51.4 m/s)

Altitude: 10,000 ft (3,050 m)

Mission Duration: 8 hours

The discussed U.S. Navy potential missions require a hover capability at all-up weight at sea level and preferably without power. That calls for a fully buoyant airship. Analysis more in depth than can be done in a conceptual study like this could define an LTA vehicle which could match both a Navy requirement and commercial; fully buoyant state will meet the hover requirement, partial buoyant it could offer a higher commercial payload.

4.9.2 U.S. Air Force Missile Mission

A preliminary long endurance mission for an LTA vehicle as missile carrier and launcher has been defined by U.S. Air Force Space and Missile Systems Organization (SAMSO). An analysis conducted in mid-1974 defined several unresolved technical questions, such as, all weather operations, mooring, handling, hangaring and maintenance difficulties, performance limitations, technical risk (technology has been dormant for 30 years), development of non-rigid envelope, manufacturing capability and

resources, survivability. The type of airship considered was a conventional non-rigid airship of approximately 14×10^6 ft^3 (397×10^3 m^3) volume.

Another analysis utilizing the results of this study and considering partial buoyant airships and of rigid design would change the answers to some of the unresolved technical questions, and may alter the rejection conclusion to a feasible alternative for the missile mission.

5. VEHICLE PARAMETRIC DESIGN

5.1 Survey of Potential Concepts and Selection of Study Configurations

5.1.1 Survey of Potential Concepts

A literature search was made to provide the maximum possible background from which to identify candidate concepts that could be of interest for the following parametric study and matching of broad mission categories. During the search, nearly 50 concepts were identified as potential candidates. However, it became evident during the survey that many concepts had similar basic characteristics which permitted grouping them into the following categories:

- Fully Buoyant - Conventional
- Partially Buoyant - STOL
- Partially Buoyant - VTOL

All early lighter than air developments were of the fully buoyant type (even though some were operated in the "heavy" condition at the time). However, in the past 10-15 years, many concepts have been put forth utilizing buoyant lift systems in both single and multiple hull arrangements with perhaps auxiliary wing and rotor systems or lifting body shapes to create advanced hybrid airship configurations of the partially buoyant type. Certain of these partially buoyant concepts have provided enough dynamic lift in the zero speed/ low speed mode to be classified as having VTOL characteristics under full control. Other partially buoyant concepts do not provide the low speed control systems and are therefore classified as having STOL characteristics.

The concepts uncovered in the literature search are listed and classified in Figure 5-1. A brief description and discussion of each concept is given in Appendix A.

5.1.2 Concept Selection

In order to be able to adequately define parametrically the feasibility of modern airships, the extensive list of potential concepts was carefully screened to select a minimum

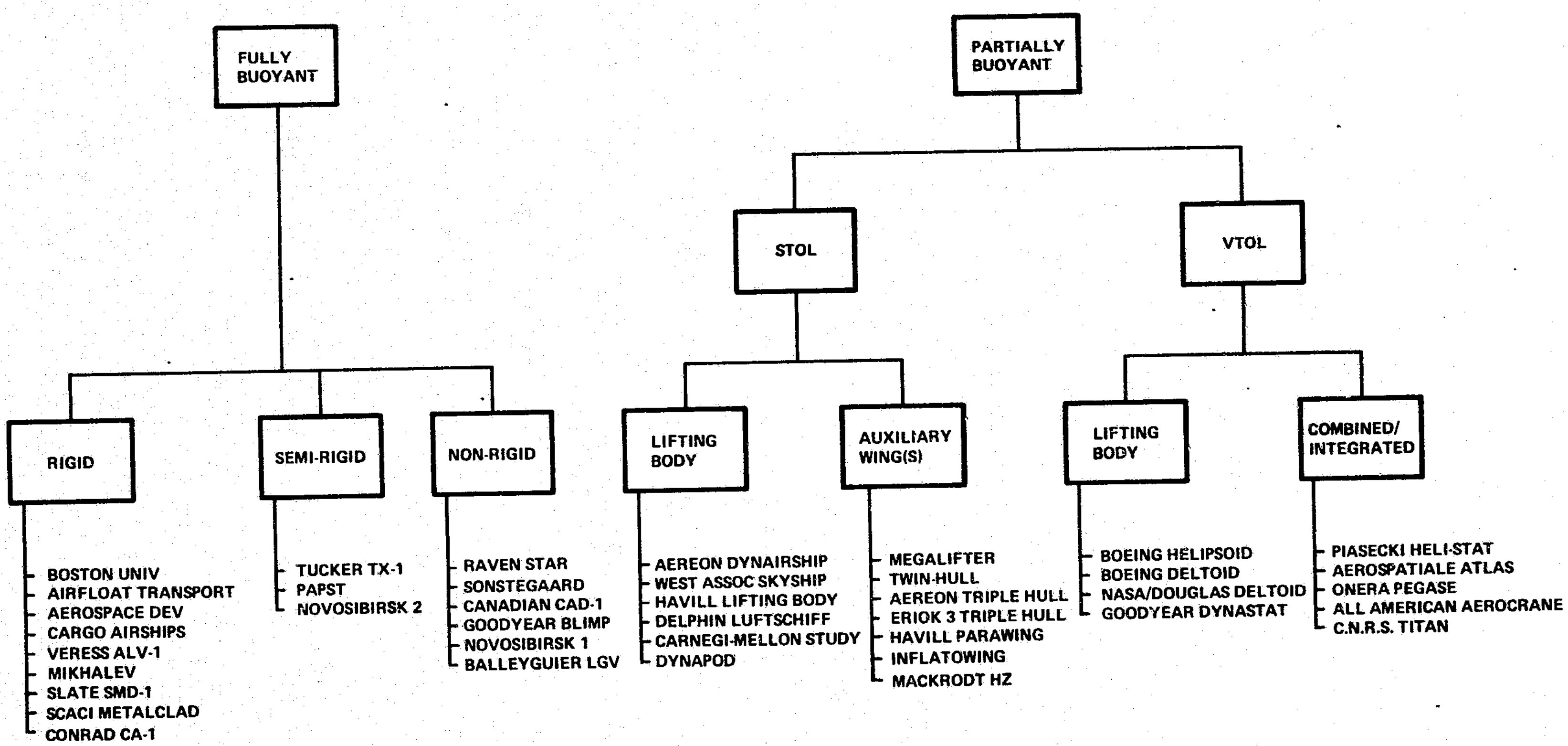


Figure 5–1. Survey of Potential Airship Concepts

number of representative concepts in each category. Preliminary 3-view sizing drawings were made for study of the more interesting potential candidates.

5.1.2.1 Representative Concept Selection

5.1.2.1.1 Fully Buoyant Concepts (See Figure 5-2)

Conventional airships have been generally classified as rigid, semi-rigid, and non-rigid. Examination of the concepts listed in Figure 5-1 has shown them to be either the classical concept or a minor variant thereof. Since the parametric study provides for variable structural and aerodynamic inputs to account for different configurations, both the rigid and non-rigid airship concepts are selected for study as being most representative of the fully buoyant concept. The semi-rigid concepts were eliminated as being special - cases not warranting separate study in this phase.

A preliminary sizing layout of the fully buoyant "conventional airship" concept for three gross lifts is shown in Figure 5-3.

5.1.2.1.2 Partially Buoyant - STOL Concept (See Figure 5-4)

The STOL Partially Buoyant airship concepts listed in Figure 5-1 can be grouped as a) Lifting Body Concepts, and b) Auxiliary Wing Concepts.

a) Lifting Body Concepts

The Aereon Dynairship concept appears to be a most representative concept in this category. Characteristics of the other body shapes would probably vary little from this baseline. Additionally, the delta planform has much background test data to draw from. While of some technical interest, the more complex concepts (Delphin Luftschiff, Dynapod concept, and the Carnegie-Mellon University study concept), appear to suffer many technical uncertainties precluding analysis in a study of this nature. Figure 5-5 is a preliminary sizing layout of a $4.3 \times 10^6 ft^3$ ($122 \times 10^3 m^3$) Dynairship concept. The West Associates Sky Ship is illustrated in Figure 5-6.

b) Auxiliary Wing Systems

The Megalifter concept appears as most representative of this category even though the multi-hull arrangements are quite dissimilar. However, the objective in any auxiliary wing system should probably be a high L/D. The multi-hull concepts (see Figure 5-7) suffer from a low L/D as well as

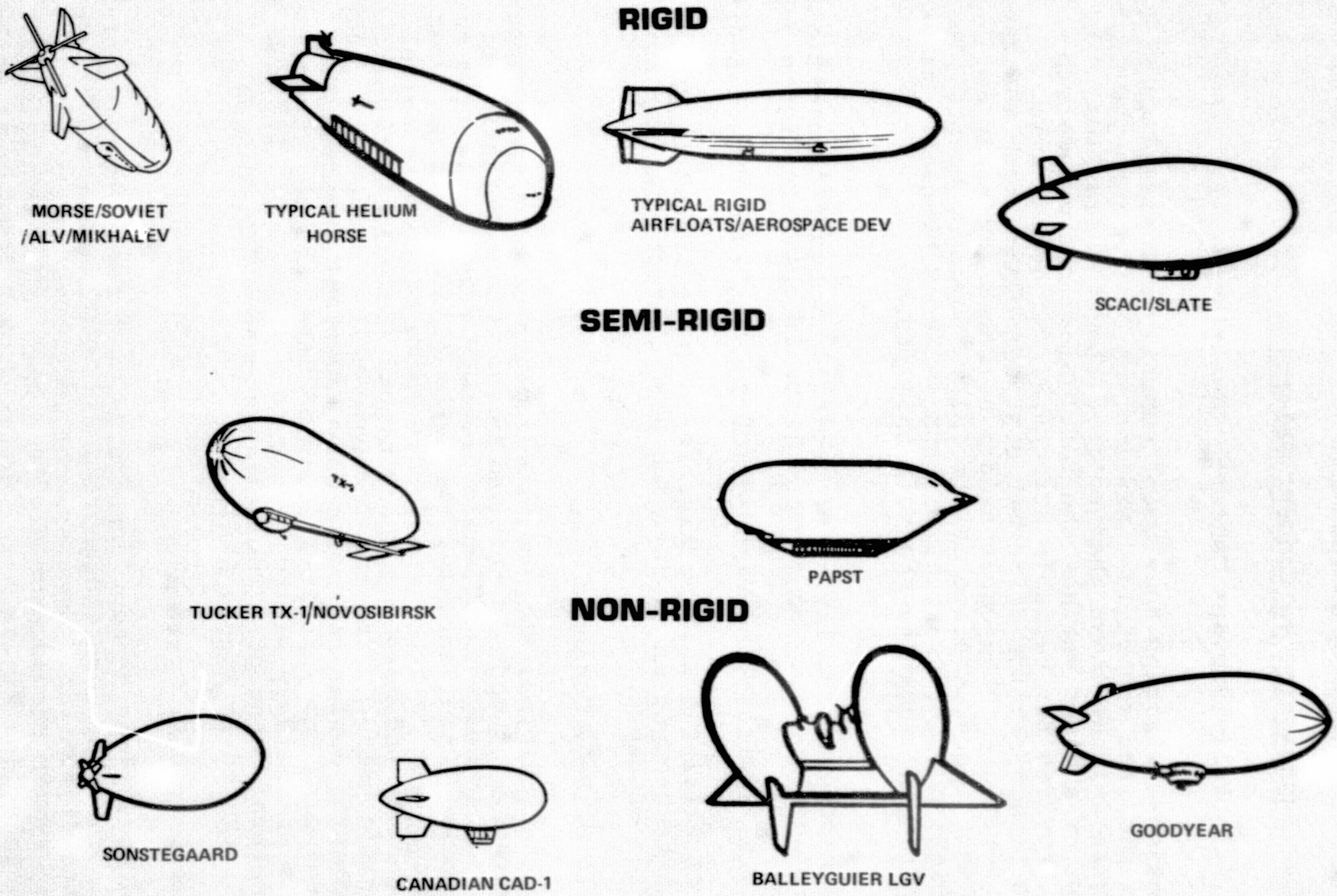


Figure 5–2. Fully Buoyant Airship Concepts Survey

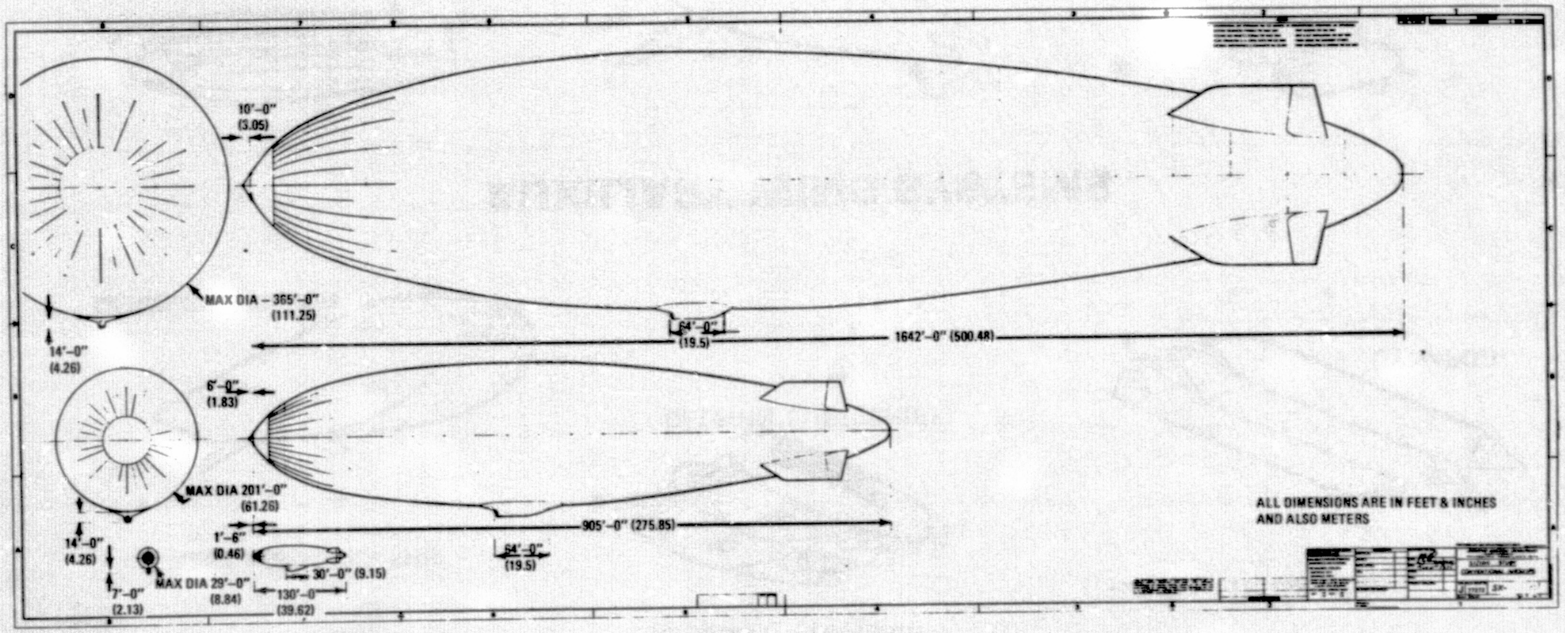


Figure 5–3. Sizing Study – Conventional Airships

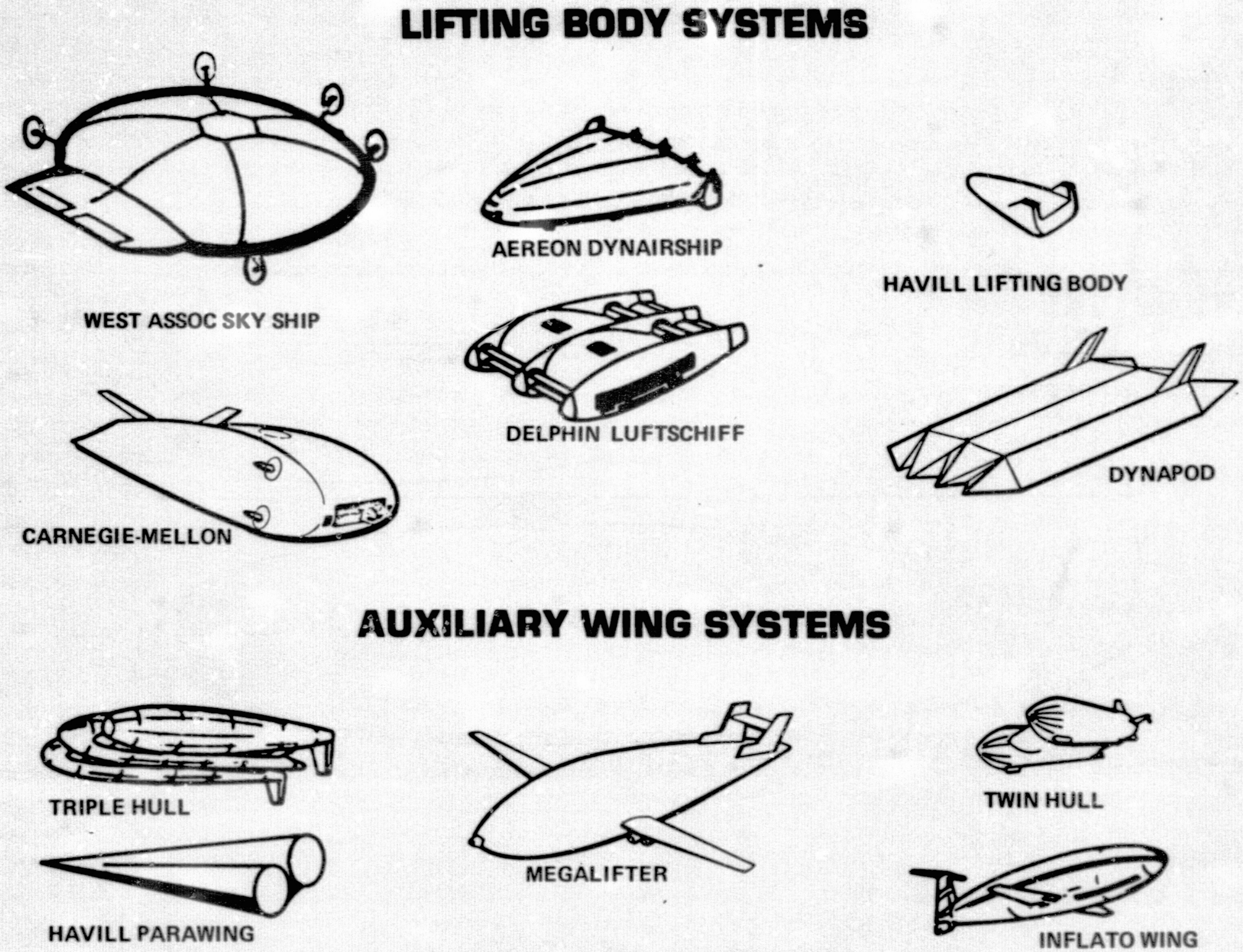


Figure 5–4. Partially Buoyant – STOL Airship Concepts Survey

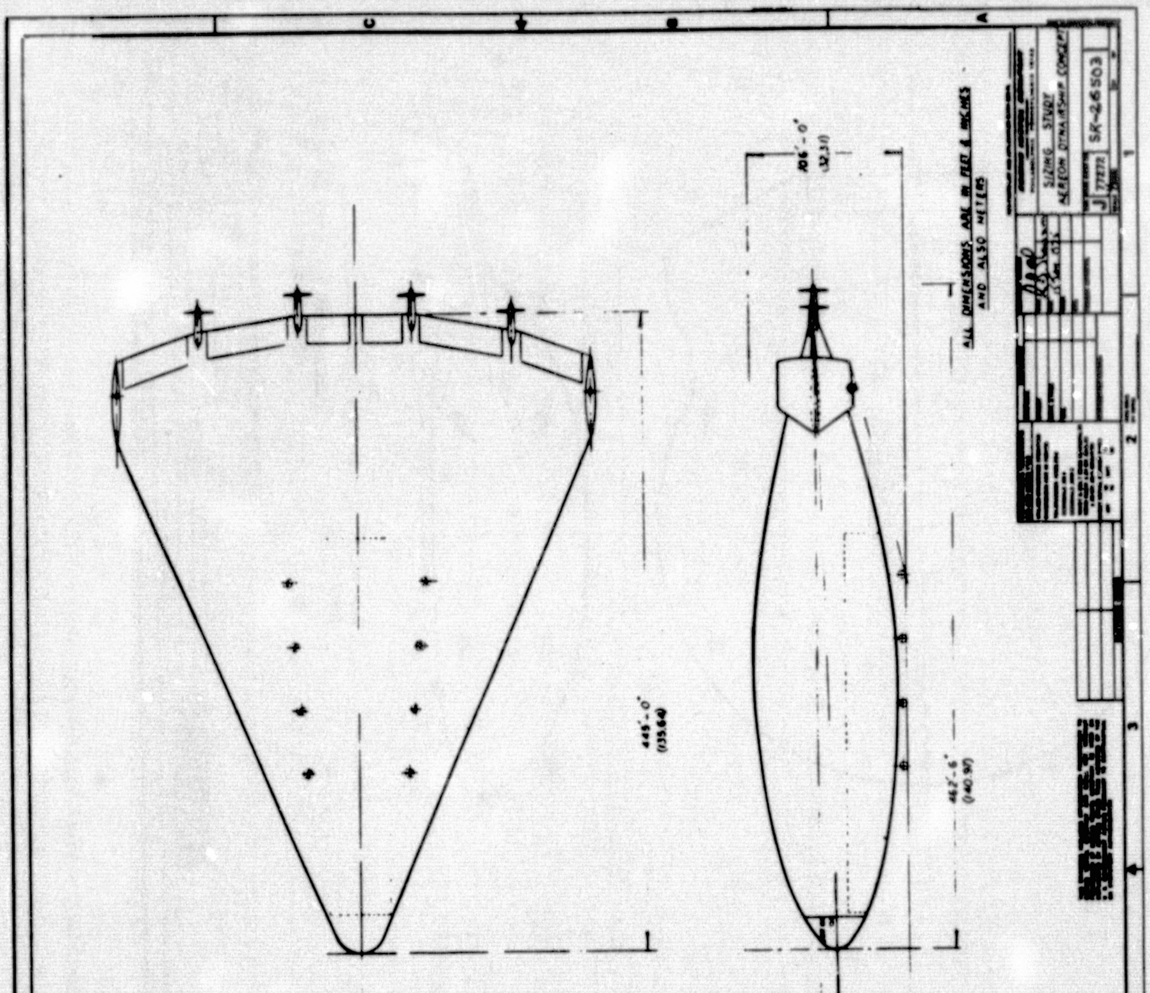


Figure 5–5. Sizing Study – Deltoid (Aereon Dynairship)

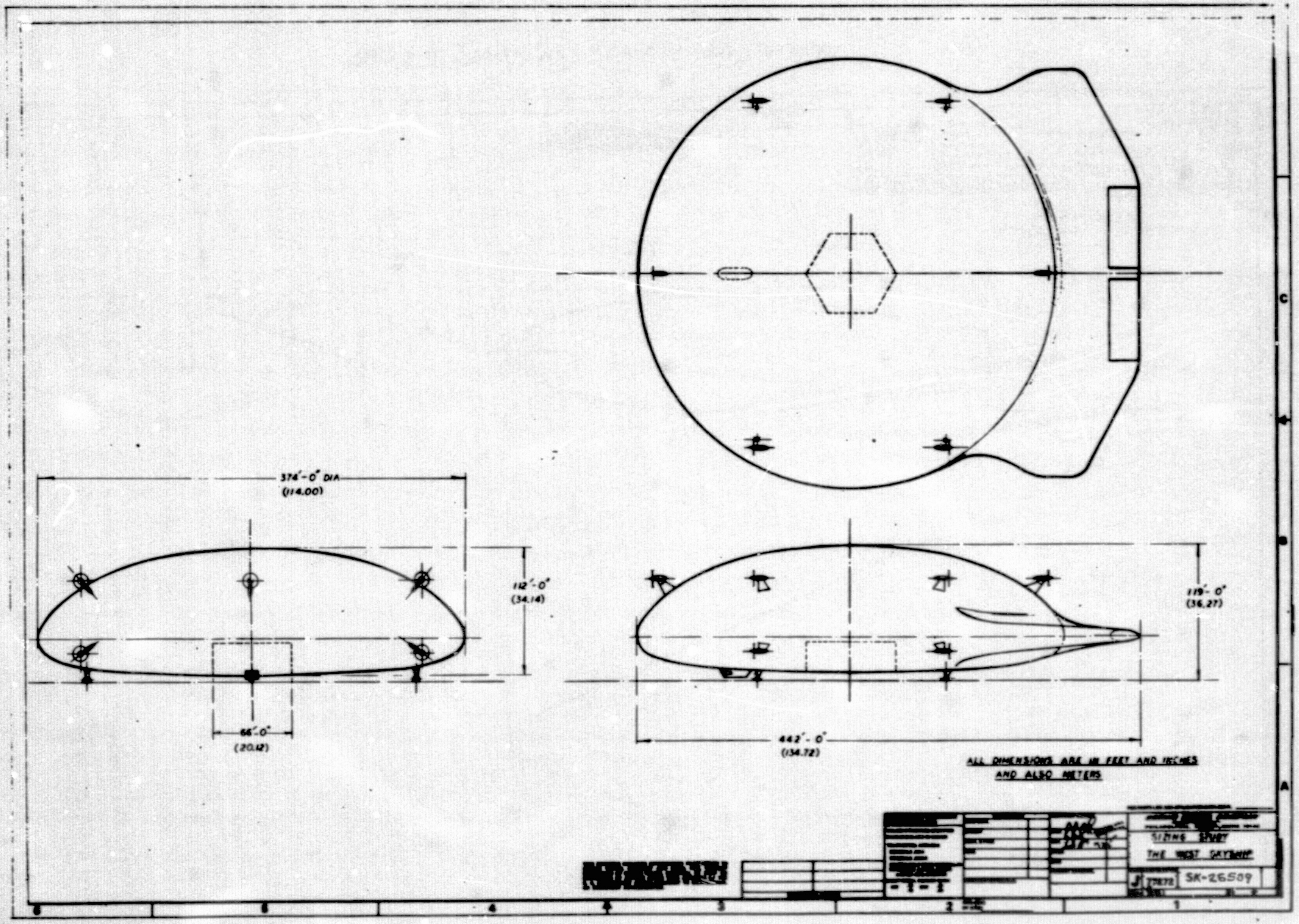


Figure 5–6. Sizing Study – West Associates Skyship

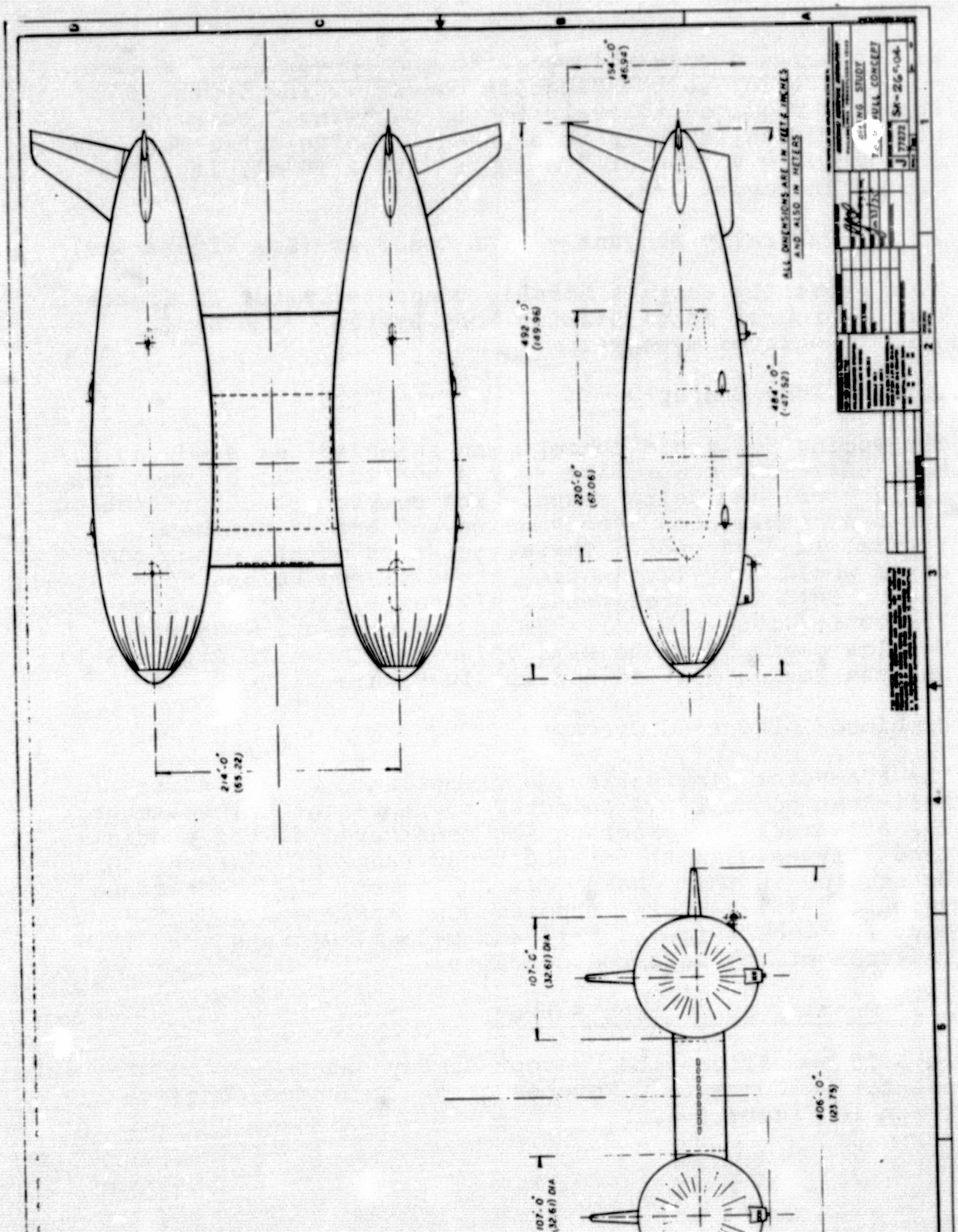


Figure 5–7. Sizing Study – Twin Hull Concept

a high surface area/volume ratio and appear at this time to be inferior to the Megalift concept. The depth of analysis required to evaluate the parawing[20] concept precluded its study in this phase. The selected Megalifter concept with volume of $7 \times 10^6 ft^3 (198 \times 10^3 m^3)$ is illustrated in Figure 5-8.

5.1.2.1.3 Partially Buoyant - VTOL Concepts (See Figure 5-9)

The VTOL Partially Buoyant Airship concepts listed in Figure 5-1 can be grouped as a) Lifting Body Systems, and b) Combined/Integrated Systems.

a) Lifting Body Concepts

The Boeing Helipsoid concept was selected for study as the most efficient compromise (for a hybrid VTOL) between the cylindrical and delta shape. The compact structural shape has reasonably good aerodynamics and better matches typical landing pads. Characteristics of the other concepts would vary little from those of the Helipsoid. Figure 5-10 is a preliminary sizing illustration of a $7 \times 10^6 ft^3 (198 \times 10^3 m^3)$ Helipsoid concept. The NASA/Douglas concept of the same volume is shown in Figure 5-11 and the Boeing Deltoid concept in Figure 5-12.

b) Combined/Integrated Concepts

The LTA-Rotor combination as exemplified by the Piasecki Heli-Stat concept was selected to represent this category. The All-American Aerocrane was considered as too specialized (Flying Cranes) for the broad range of missions to be studied in this phase. In any event, the Aerocrane (Figure 5-13) is being studied separately under U. S. Navy funding. Figures 5-14 and 5-15 illustrate the features of the selected concepts.

5.1.2.2 <u>Summary of Concept Survey</u>

Figure 5-16 summarizes the Concept Survey and Selection of Representative Concepts. Sketches of the selected concepts are shown in Figure 5-17.

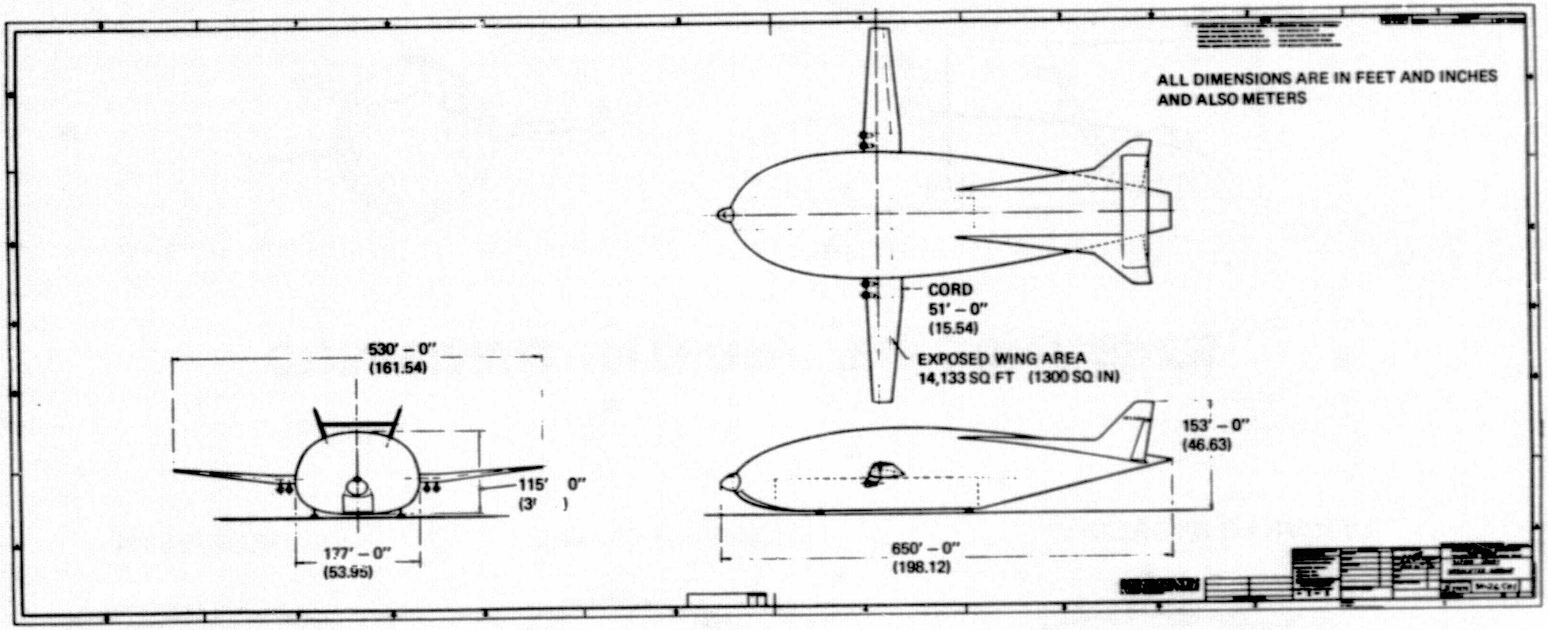


Figure 5–8. Sizing Study – Megalifter Concept

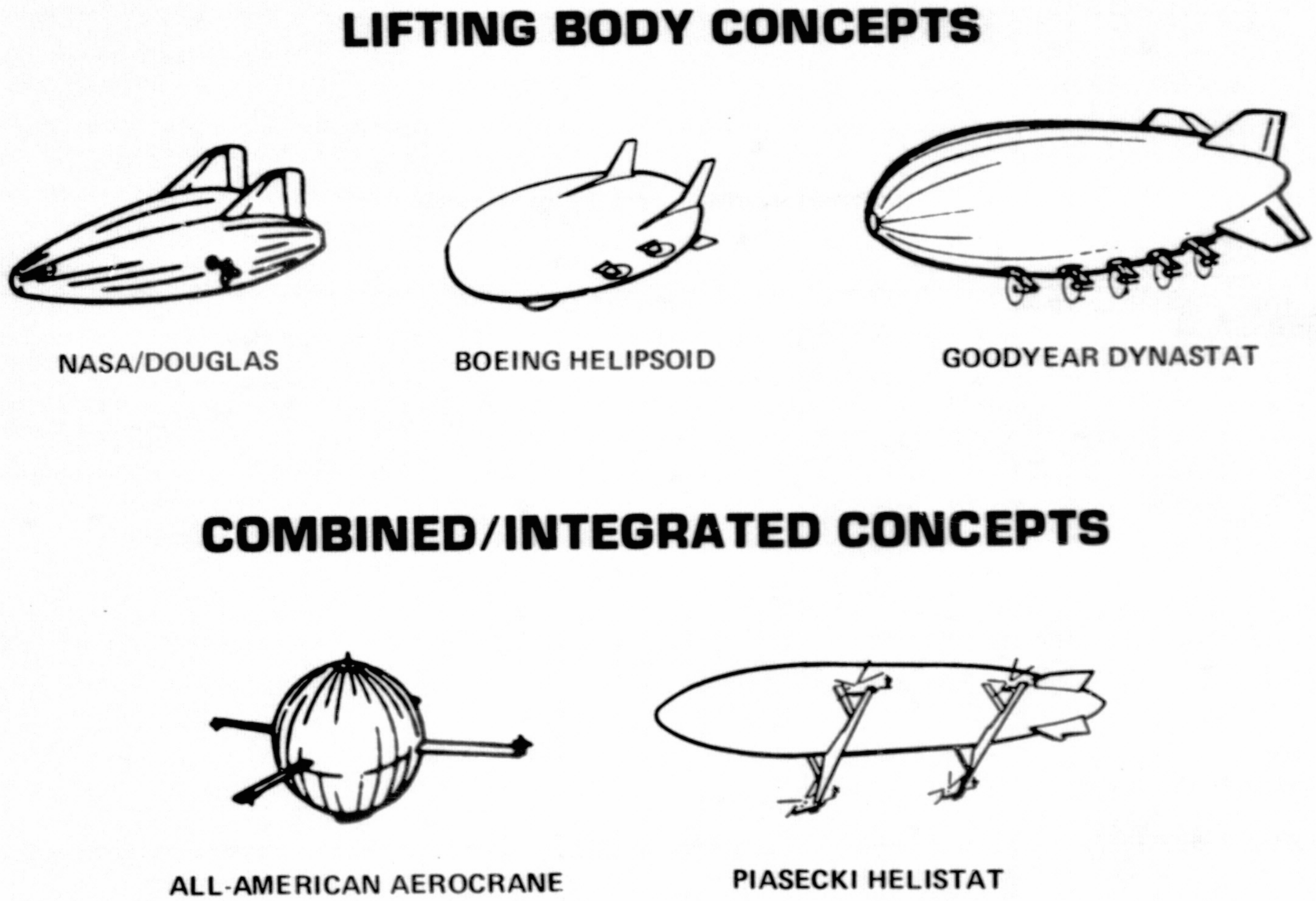


Figure 5–9. Partially Buoyant – VTOL Airship Concepts Survey

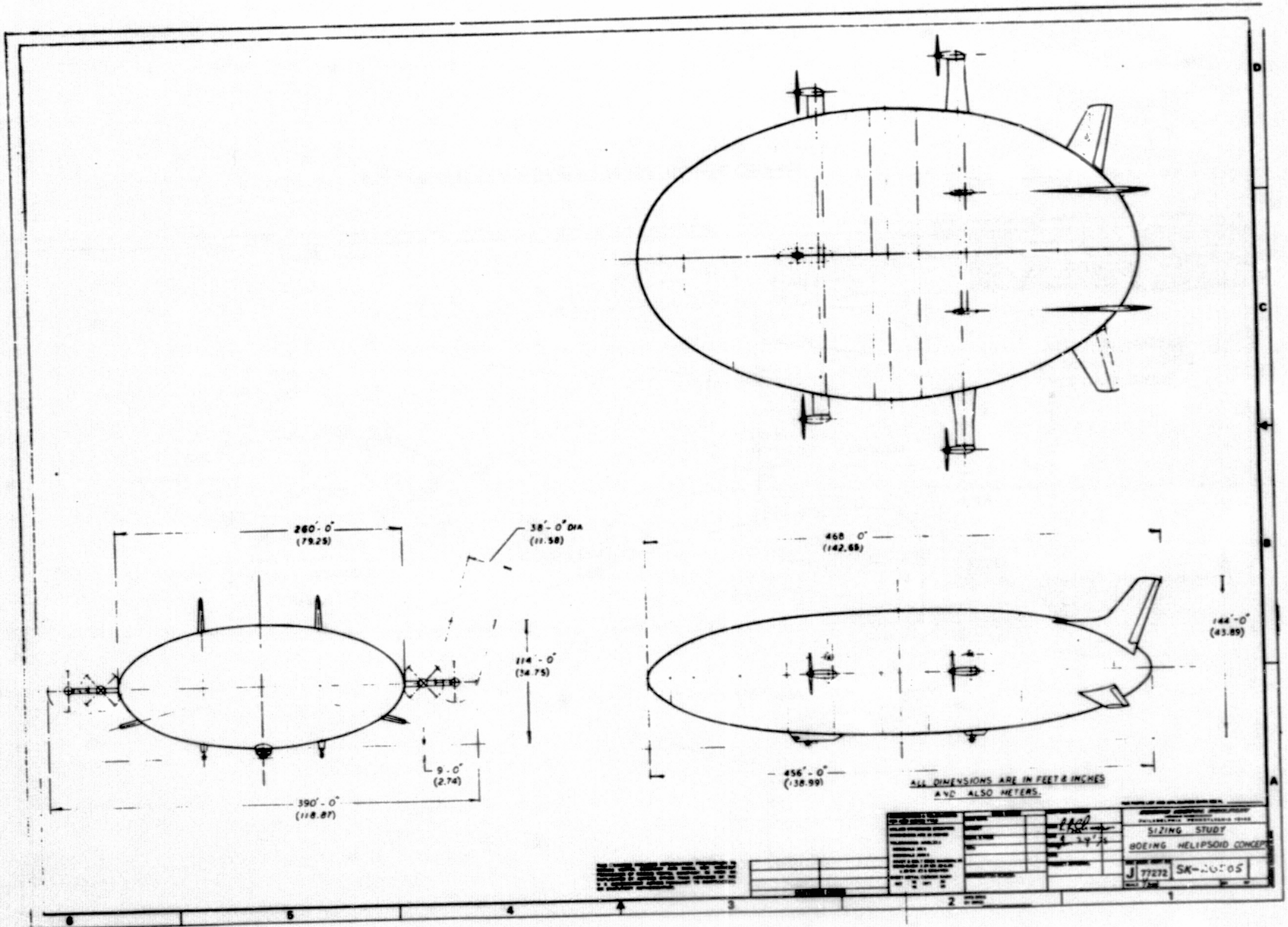


Figure 5–10. Sizing Study – Helipsoid Concept

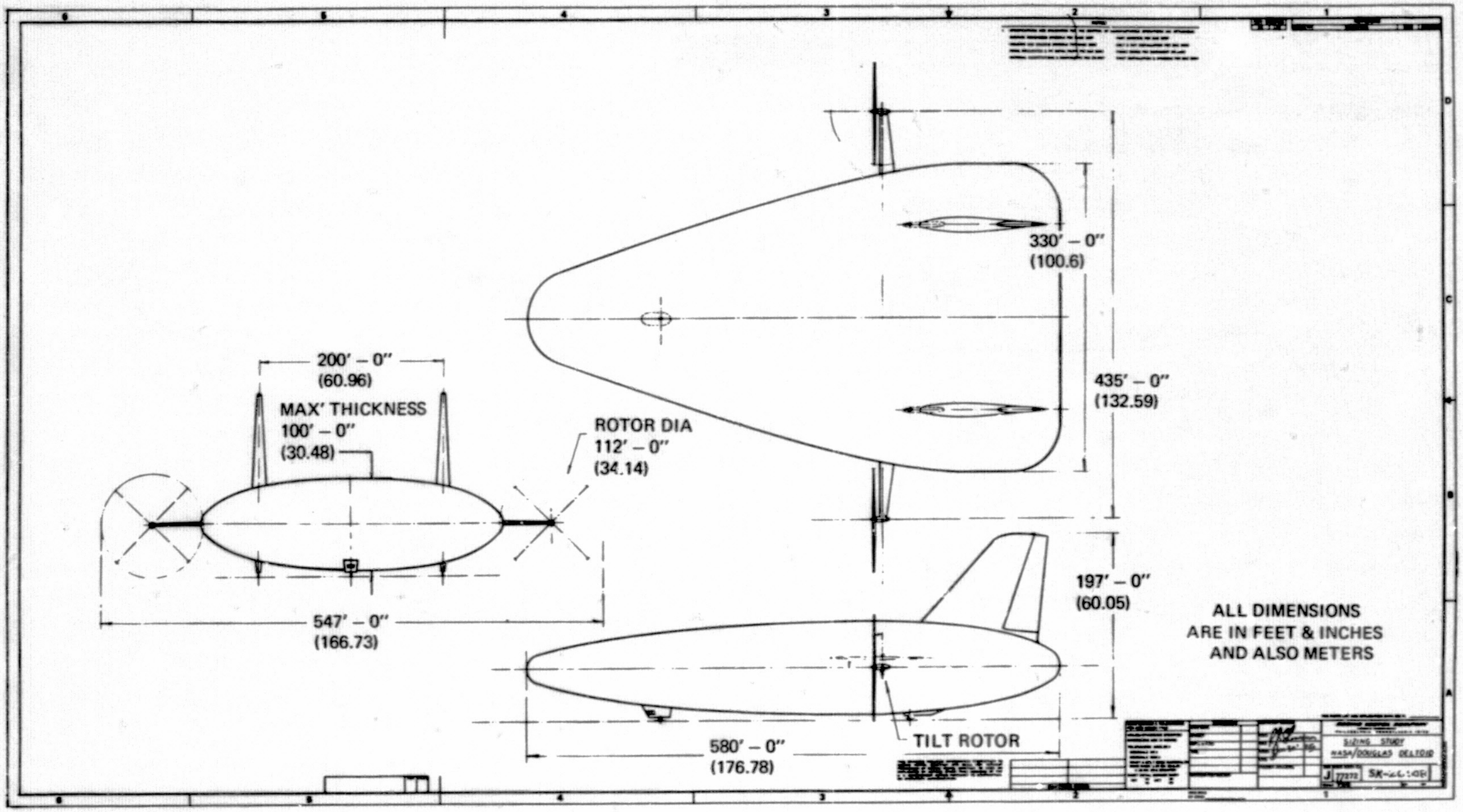


Figure 5–11. Sizing Study – NASA/Douglas Concept

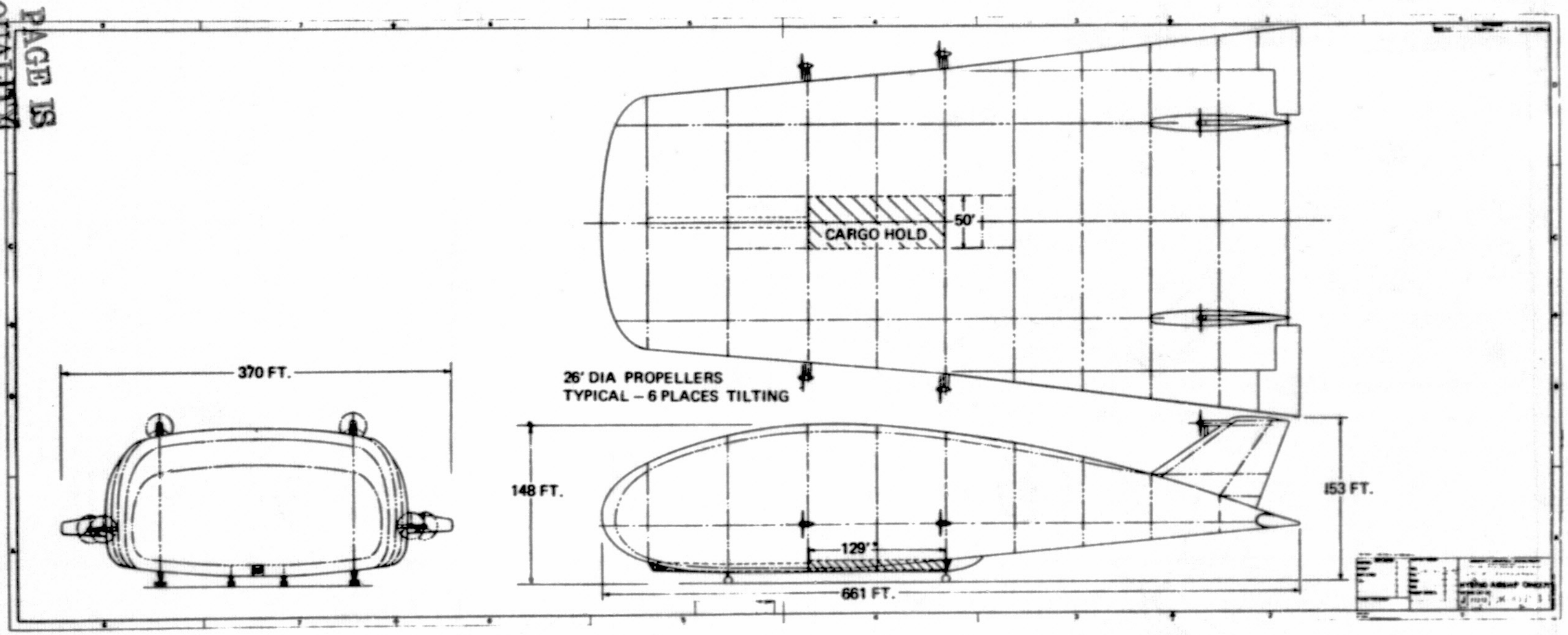


Figure 5–12. Sizing Study – Deltoid Concept

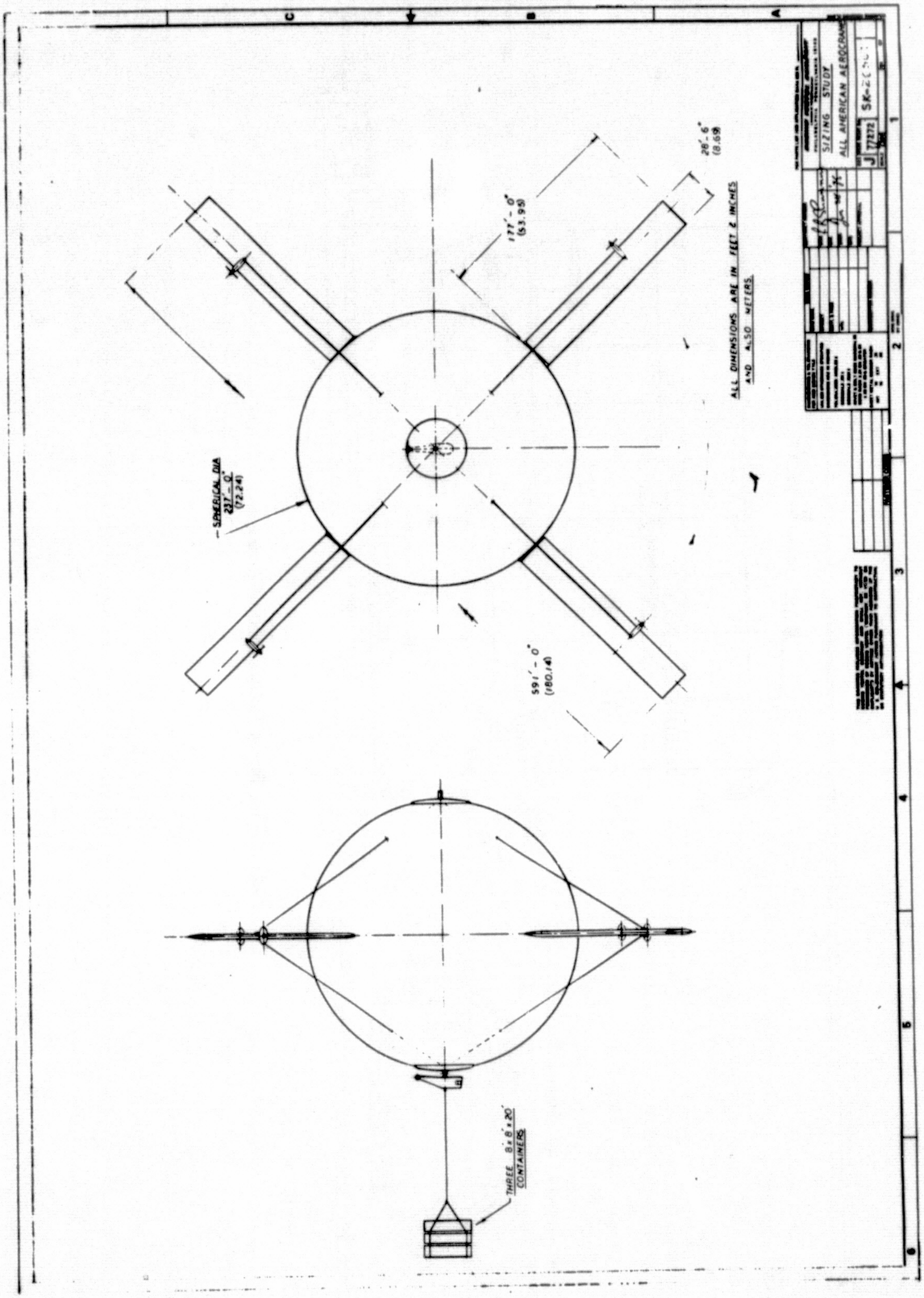


Figure 5–13. Sizing Study — All American Aerocrane

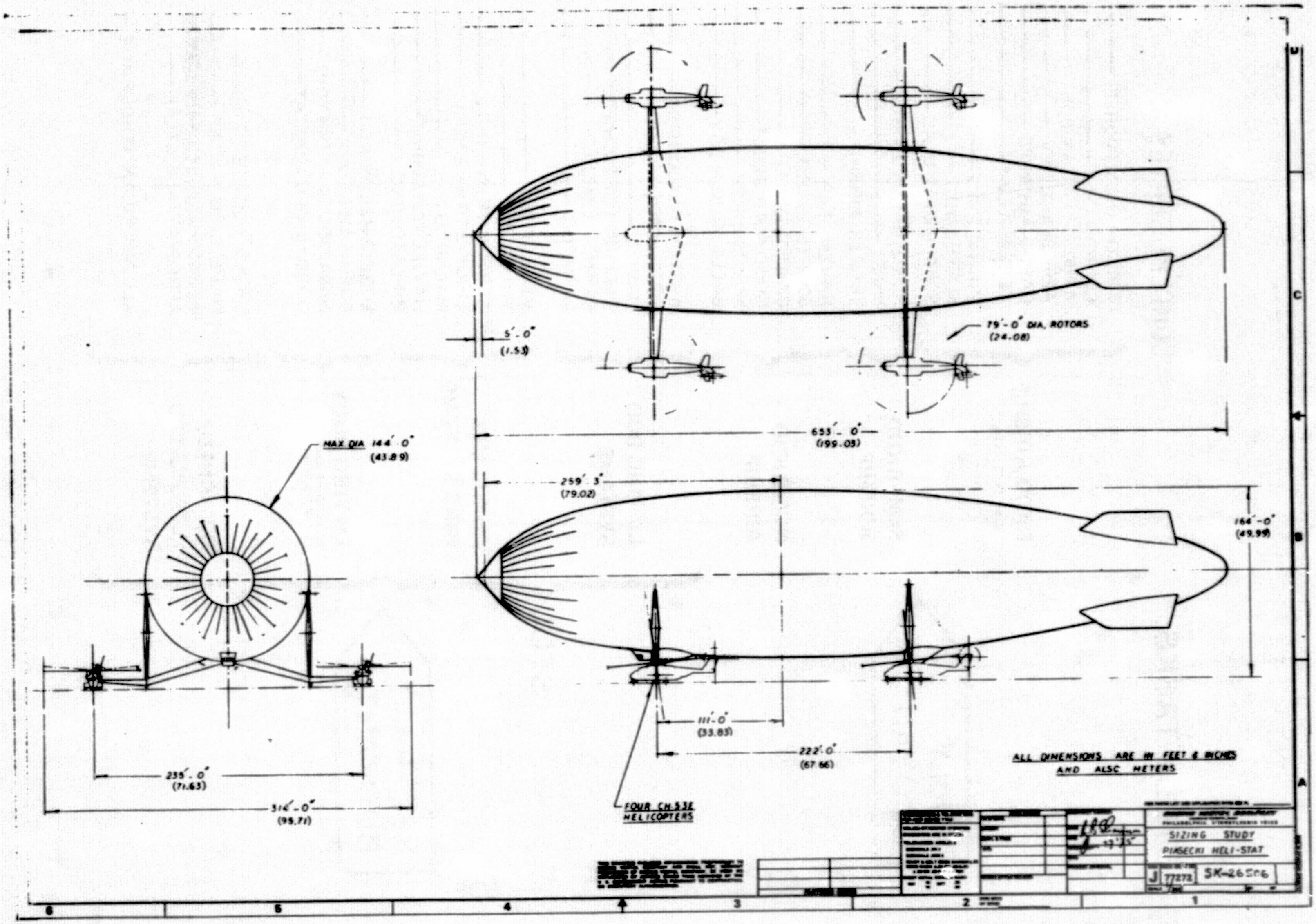


Figure 5–14. Sizing Study – Piasecki Heli-Stat

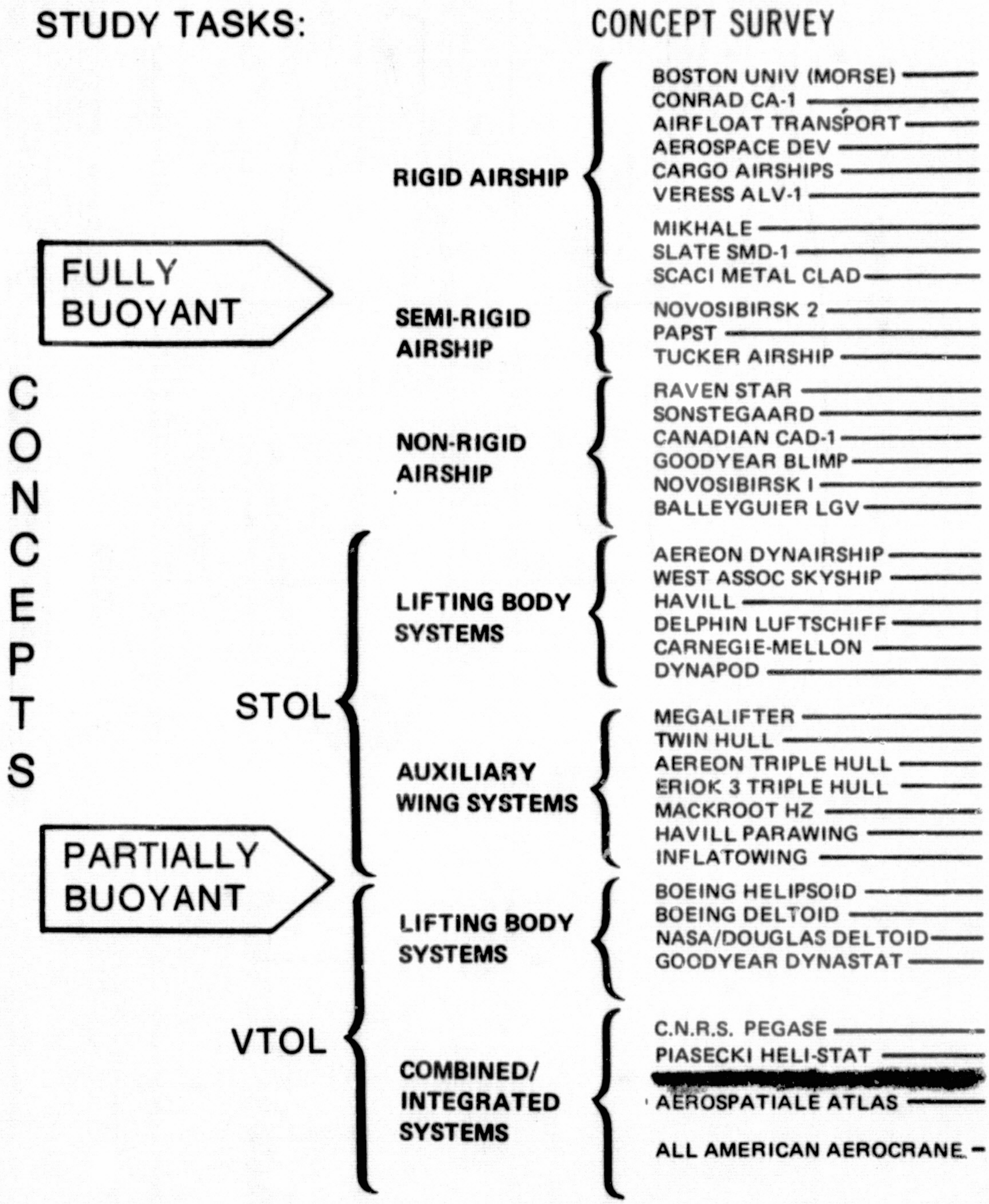


Figure 5–15. Concept Selection Flow Chart Surveyed Concepts

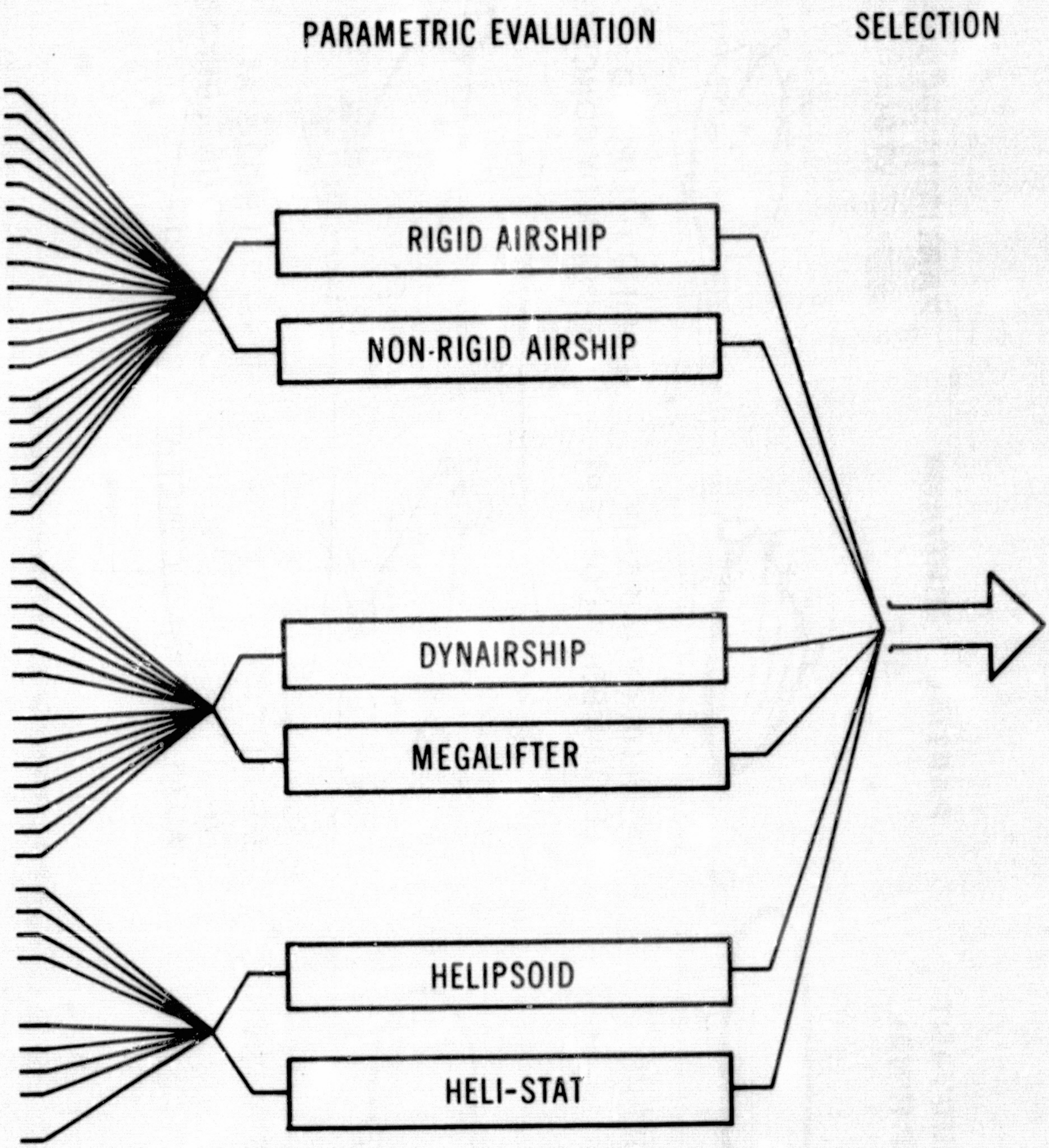


Figure 5–16. Concept Selection Flow Chart Selected Concepts for Evaluation

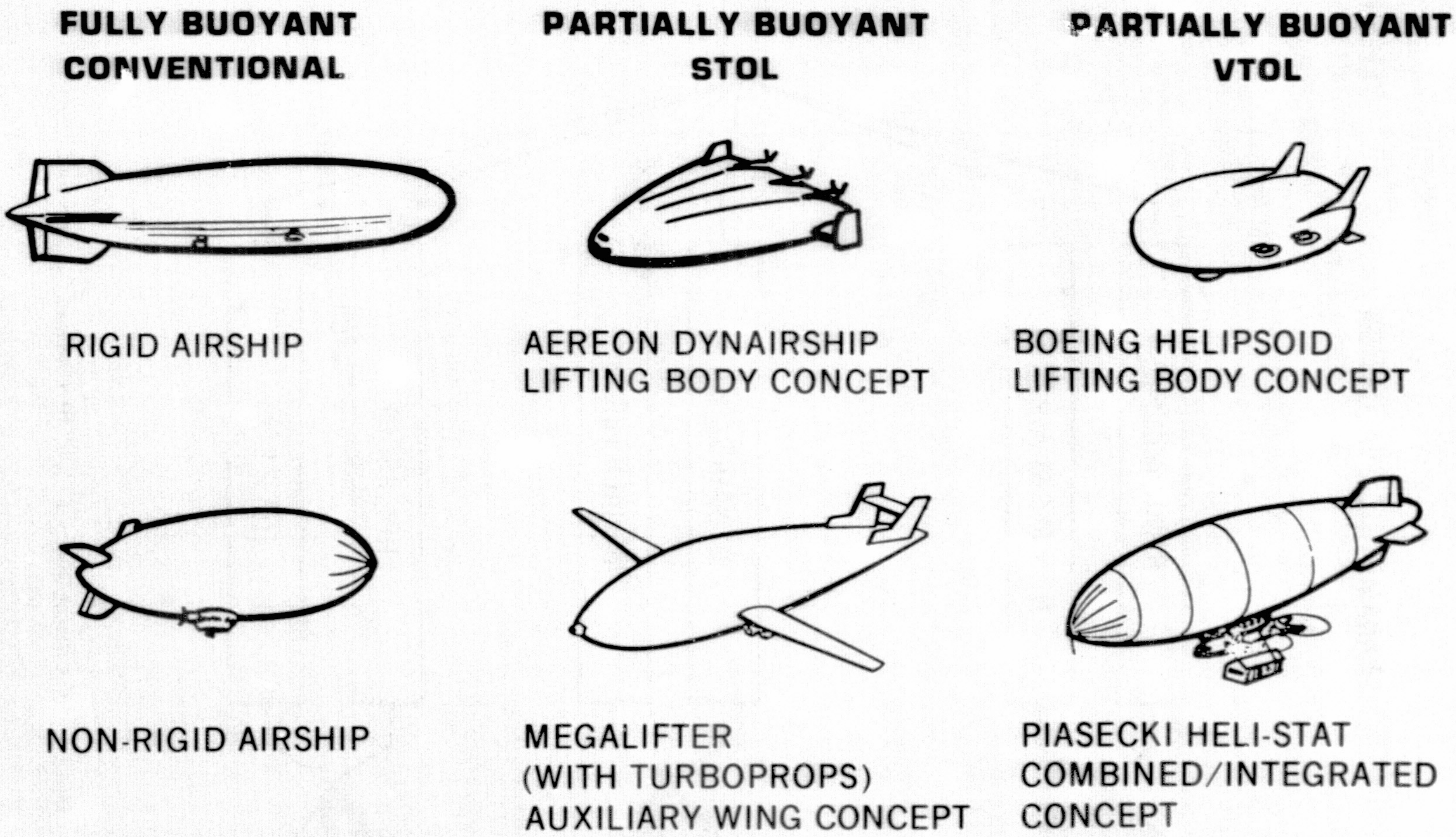


Figure 5–17. Concepts Selected for Parametric Evaluation

5.2 Design Trade-Off Studies

Comparative studies were made in several areas to select input parameters for the preliminary design and parametric analysis.

5.2.1 Propulsion System Engine Cycle Trade-Off

5.2.1.1 Summary and Conclusions

The typical airship has a comparatively large drag area which, coupled with long range requirements, will only be offset by the highest possible propulsive efficiency. Although much progress has been made recently in development of high bypass turbofan engines, Figure 5-18 clearly shows that a propeller (or prop-rotor) is the most efficient thrustor for the relatively low speed regime of the airship. Although a case might be made for a ducted fan/propeller (very high bypass) at the higher speed levels (combined with some form of drag reduction), both the propeller and the ducted fan will require some form of shaft power system.

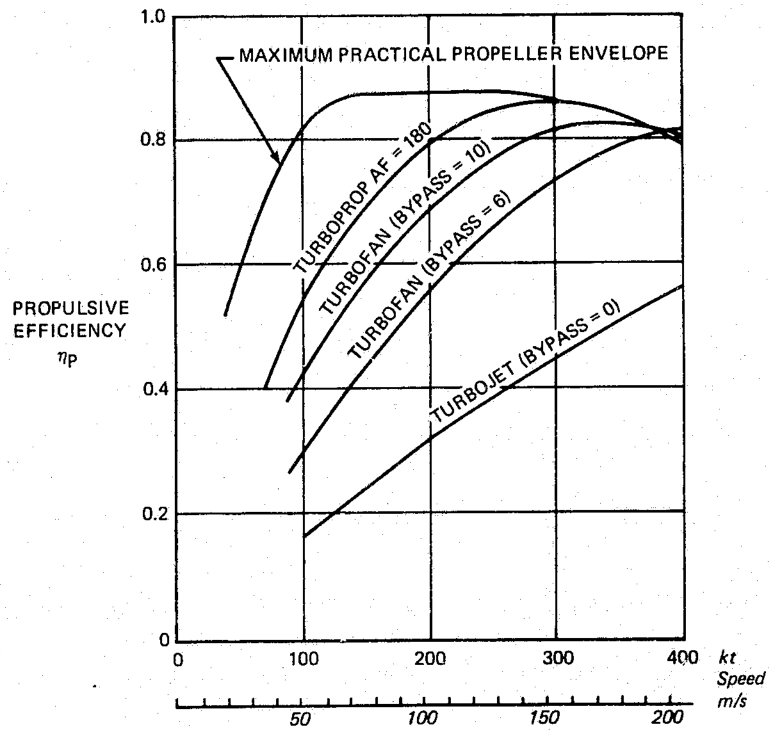


Figure 5–18. Thrustor Propulsive Efficiency

Therefore, in this engine cycle trade-off study, only shaft power concepts were evaluated. Figure 5-19 summarizes the study and conclusions: The petroleum-fueled closed-Brayton cycle shaft turbine was selected due to its superiority in propulsion system weight, technical risk of development, and fuel availability and cost. Although, at this time, a nuclear-Brayton cycle cannot be justified (even with its near-zero SFC),

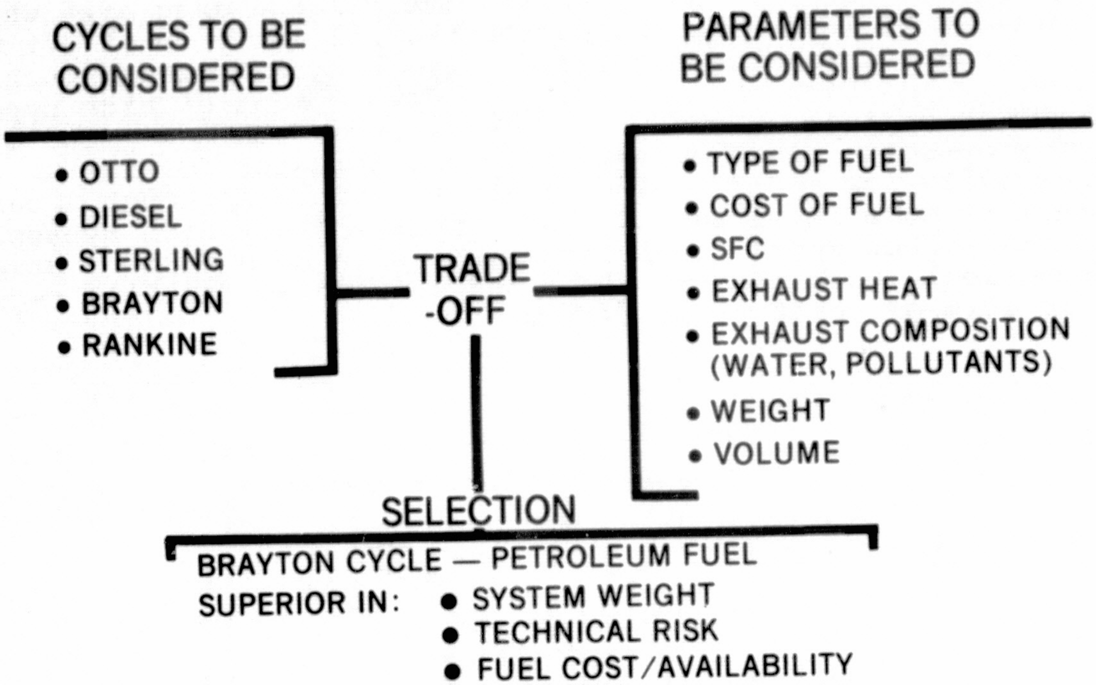


Figure 5–19. Engine Cycle Trade-Off (Shaft Power Concepts)

if there is ever to be an airborne nuclear power plant, a large airship is the logical user of that system. Aside from the fact that there is negligible fuel burn-off and therefore no ballasting problem, the airship can inherently provide the large separation distances necessary to reduce unit shield weights. In addition, crashworthiness support structure concepts might provide containment safety in event of an accident.

5.2.1.2 Introduction

The engine cycle for the airship analysis was selected by evaluating the Otto, Diesel, Brayton, Rankine, and Sterling thermodynamic cycles, including nuclear as well as petroleum fuel for the Brayton and Rankine cycles. The following

criteria were considered in the selection of the powerplant:

- Fuel consumption
- Propulsion system weight
- Technical risk of development
- Fuel type, availability and cost
- Impact on airship design
- Exhaust emissions and pollutants
- Propulsion system volume
- Altitude effect on engine power

Most of these parameters are quantified in Table 5-I for 1975 state-of-the-art propulsion systems, including those differences which can be attributed to engine size. Weighting factors were determined for each of the evaluation criteria listed above (defining their importance in relationship to each other) to be used in the selection of the airship powerplant.

5.2.1.3 Engine Cycle Survey

5.2.1.3.1 Otto Cycle

The commonest type of internal combustion engine is the Otto cycle, used in most automobiles and small aircraft. However, the development of the gas turbine engine (Brayton cycle) with its superior weight characteristics has obviated the further development of large piston engines for aircraft, and technology advances in the compressor pressure ratio and turbine-inlet temperature of the gas turbine have improved its SFC to the point where it is nearly identical to the Otto engine.

5.2.1.3.2 Diesel Cycle

The Diesel engine is a compression ignition engine rather than a spark-ignition engine. Higher compression and firing pressures required to produce compression ignition result in an engine that is heavier and larger than the Otto engine. Consequently, aircraft Diesel engine development has been dormant for thirty years. Diesel fuel economy is better than the Otto engine though, because of its high thermal efficiency. And the lack of an ignition system increases reliability. Furthermore, since the fuel is not carbureted with the air, burning is improved and the Diesel emissions are substantially lower than those of the Otto engine.

5.2.1.3.3 Brayton Cycle - Petroleum Fuel

The Brayton cycle, as typified by the conventional open cycle gas turbine engine, has benefited from extensive development for both airplane and helicopter applications over a period of

Table 5–I. Engine Cycle Characteristics

ENGINE CYCLE	SIZE shp	CRUISE SFC lb/hr/shp *kg/hr/shp*	SPECIFIC WEIGHT lb/shp *kg/shp*	SPECIFIC VOLUME ft^3/shp *m^3/shp*	TYPE OF FUEL	EXHAUST EMISSIONS	STATE-OF-THE-ART AVAILABILITY
OTTO (ICE-INTERNAL COMBUSTION ENGINE)	< 1,000	0.42 *0.19*	1.50 *0.68*	0.05 *0.0014*	GASOLINE	CO, UNBURNED HYDROCARBONS, NO_x	LARGE ICE TECHNOLOGY ADVANCES OBVIATED BY BRAYTON CYCLE FOR CONVENTIONAL AIRCRAFT
	1,000–5,000	0.42 *0.19*	0.70 *0.32*	0.03 *0.0008*			
DIESEL	< 1,000	0.34 *0.15*	1.50+ *0.68+*	0.10 *0.0028*	DIESEL OIL	CO, UNBURNED HYDROCARBONS, NO_x	AIRCRAFT DIESEL ENGINE DEVELOPMENT DORMANT SINCE 1945
	1,000–5,000	0.34 *0.15*	0.70+ *0.32+*	0.06 *0.0017*			
BRAYTON-PETROLEUM FUEL	< 1,000	0.46 *0.21*	0.24 *0.11*	0.005 *0.00014*	KEROSENE	CO, UNBURNED HYDROCARBONS, NO_x	"OFF-THE-SHELF" AVAILABILITY
	1,000–30,000	0.42 *0.19*	0.15 *0.07*	0.005 *0.00014*			
BRAYTON-NUCLEAR FUEL (Conventional chemical combustor during take-off and landing)	5,000–100,000	0	2.20 *1.00*	VERY LARGE	NUCLEAR	NONE	OPTIMIZED UNIT SHIELD CONFIGURATION IN PRELIMINARY CON-CEPTUAL DESIGN STAGE
RANKINE-PETROLEUM FUEL	< 1,000	0.35 *0.16*	1.00 *0.45*	0.06 *0.0017*	KEROSENE	CO, UNBURNED HYDROCARBONS, NO_x	TECHNOLOGY AVAILABLE ONLY FOR VERY SMALL POWER RATINGS
	1,000–30,000						
RANKINE-NUCLEAR FUEL (Conventional chemical combustor during take-off and landing)	5,000–100,000	0	3.00 *1.36*	VERY LARGE	NUCLEAR	NONE	OPTIMIZED UNIT SHIELD CONFIGURATION IN PRELIMINARY CON-CEPTUAL DESIGN STAGE
STIRLING	< 1,000	0.31 *0.14*	6.00 *2.72*	0.20 *0.0057*	GASOLINE	CO, UNBURNED HYDROCARBONS, NO_x	TECHNOLOGY AVAILABLE ONLY IN SMALL ENGINE SIZES

*Net (not installed)

twenty-five years. The specific horsepower of the shaft turbine engine (output shaft horsepower per pound per second of engine airflow) is primarily dependent upon turbine-inlet temperature and only secondarily dependent upon compressor pressure ratio. Engine airflow directly impacts engine weight. Consequently, one main thrust of gas turbine research and development has been to improve turbine component metallurgy and cooling to achieve higher turbine temperatures, higher specific horsepowers, and lower engine weights. The weight characteristics of shaft turbine engines have improved to the point of being a fraction of the weight of an Otto engine of comparable power output. Turboshaft engine SFC is primarily dependent upon compressor pressure ratio, so parallel research and development effort has been devoted to increasing pressure ratios and reducing fuel consumption. The shaft turbine engine SFC today is nearly equal to the Otto engine but not to the Diesel.

5.2.1.3.4 Brayton Cycle - Nuclear Fuel

Nuclear propulsion, through fission, offers the possibility of vastly greater energy per unit mass of fuel than can be extracted from chemical fuels, and so automatically eliminates aircraft range and endurance constraints. However, nuclear energy introduces significant radiation hazards, such that radiation protection (inevitably a very heavy unit shield) must be provided for personnel, and reasonable protection against the spread of fission products must be provided in the event of a reactor malfunction or an aircraft accident. In the powerplant, then, the major weight item is the shield while other significant weight items are the rotating machinery and the heat exchanger. The weight of the reactor is inconsequential, although its volume is not, and the volume affects the size and the weight of the shield. Previous aircraft nuclear propulsion concepts used a divided shield to make its weight acceptable, locating some shielding around the reactor and some around the crew. Radiation dose levels outside the crew compartment were to be extremely high, impacting maintenance operations, personnel mobility, and permissible geographic areas of operation. However, a practical nuclear aircraft requires unit shielding to allow all operations to be carried out without concern for reactor radiation. The concept of a complete reactor shielding to limit radiation doses to acceptable limits, with sufficient impact resistance, and at acceptable weight, now appears feasible. The previous aircraft nuclear propulsion investigations concentrated on two propulsion concepts utilizing the Brayton cycle for propulsive power:

a. In the direct or open cycle the reactor itself transfers its heat directly to the propulsive airstream, in effect taking the place of the combustor in a conventional gas turbine engine.

b. The indirect or closed cycle uses a heat-transfer fluid (liquid metal) to transfer the heat from the reactor through primary and secondary heat exchangers to the air of the propulsion system. This latter concept is illustrated in Figure 5-20.

The problem of containing fission products in the case of a fuel-element failure appears to be impossible in the direct cycle, so system safety considerations dictate the indirect cycle for aircraft applications. Liquid metal cooling system problems include chemical activity of the metals, fire hazards involved in their use, and their high freezing

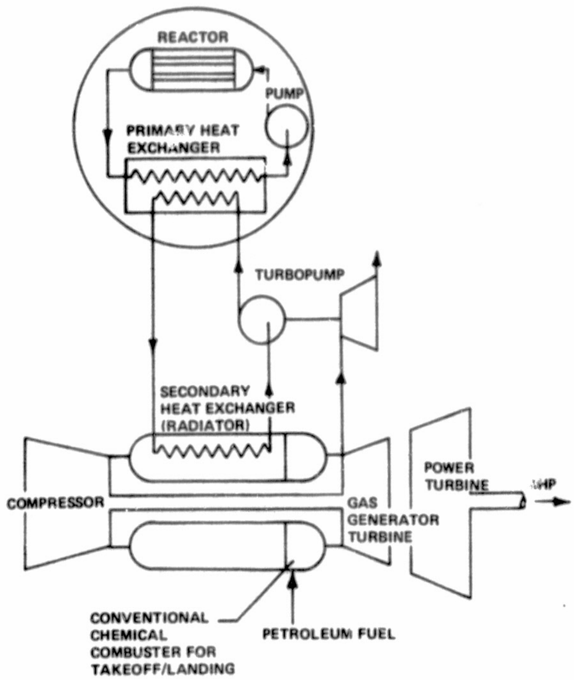


Figure 5-20. Brayton Cycle – Nuclear Fuel

point temperatures, but a high-pressure helium system is offered as a viable alternative at the expense of the high-pressure design problems and pumping requirements.

Figure 5-21 illustrates schematically a possible installation of a nuclear fueled Brayton cycle propulsion system in a typical conventional rigid airship. Alternative arrangements are shown for the take-off/landing operations; use of either a combined nuclear/chemical propulsion engine or an auxiliary

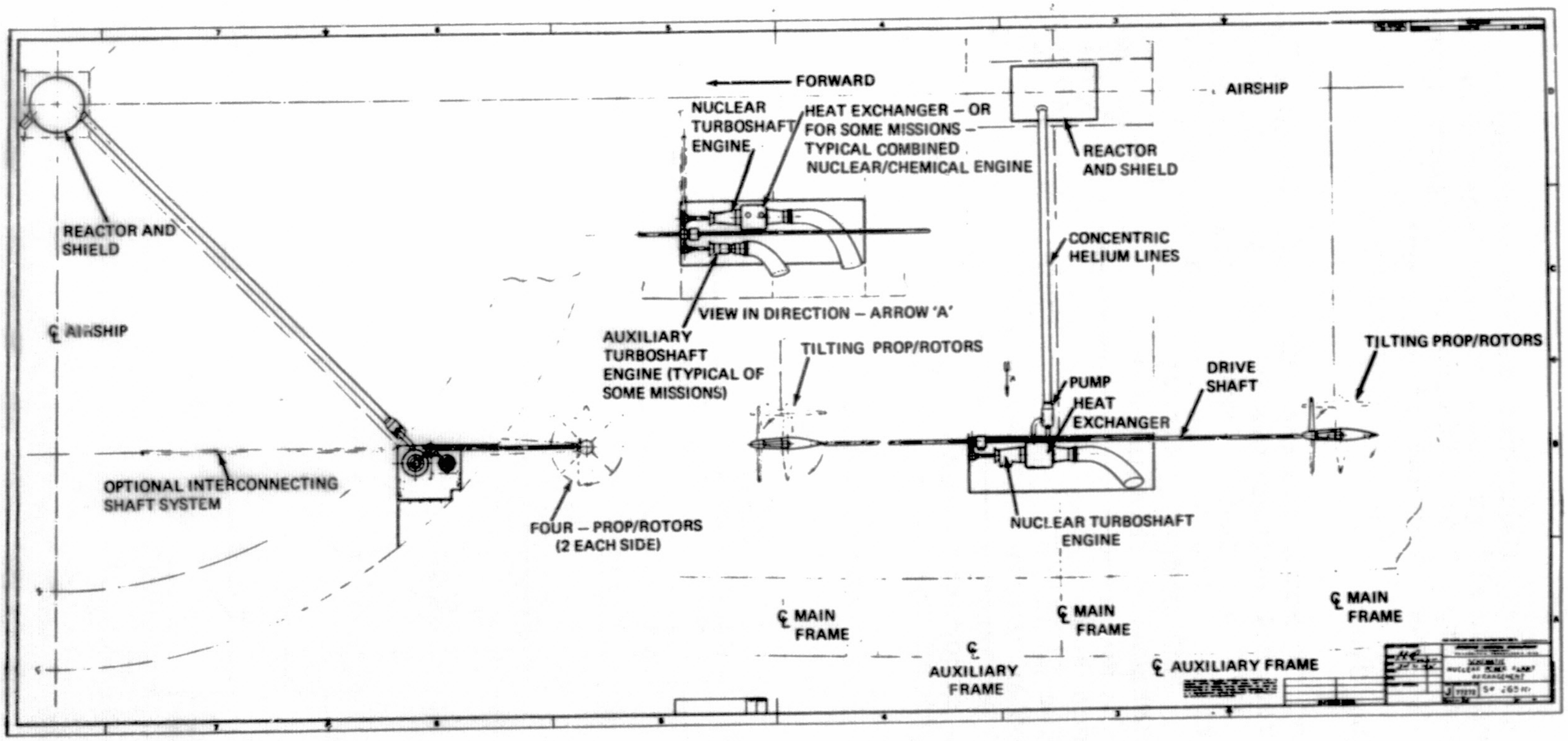


Figure 5–21. Schematic – Nuclear Power Plant Arrangement

turboshaft engine. Also indicated is the remoteness of the reactor which lends itself to reduced unit shield weight as well as the possibility of an attenuating support system to provide crashworthiness in event of accident.

5.2.1.3.5 Rankine Cycle

The Rankine cycle, or steam engine, has stimulated renewed interest as a potential automotive powerplant and, in some instances, as an aircraft powerplant. In either application, the technology state-of-the-art is limited to small output shaft horsepower. The propulsion system components are illustrated schematically in Figure 5-22. The Rankine cycle suffers from the handicap that all the waste heat (Q_R) must be rejected through heat transfer, none is exhausted to the atmosphere, and the condenser requirements become prohibitive. The schematic also pictures an alternative to the simpler condenser feed water pump arrangement using a jet mixer, smaller radiator, condensate pump, and economizer, reducing the size and weight of system at the expense of increased complexity.

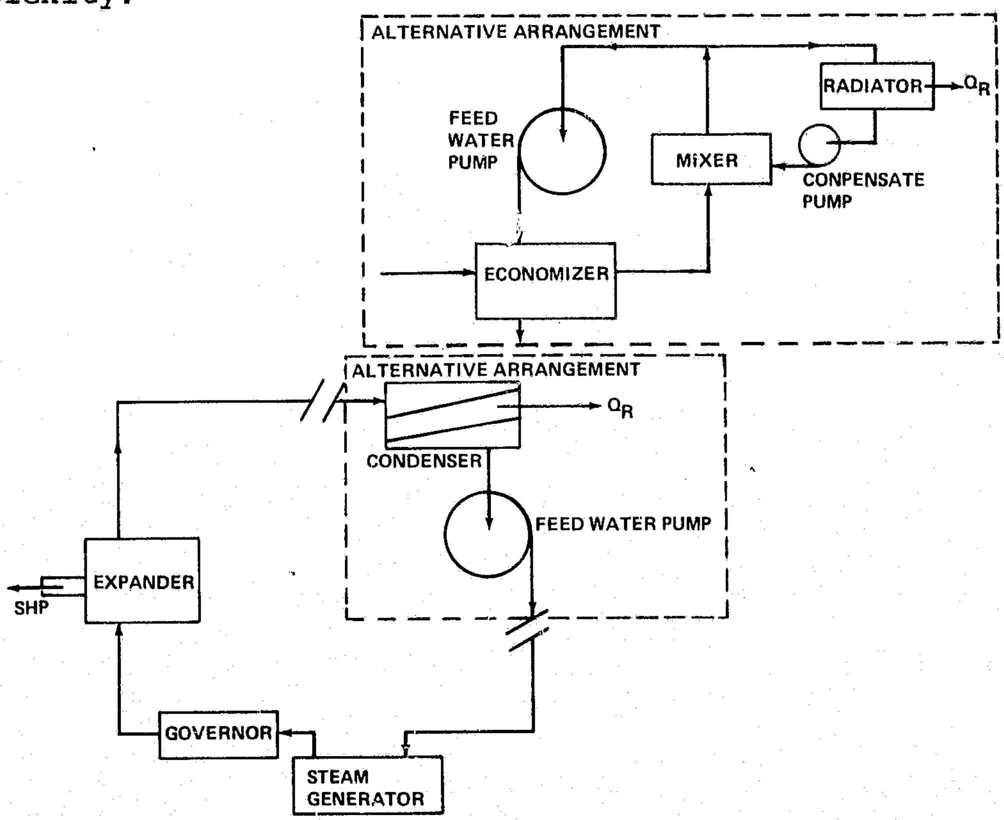


Figure 5–22. Rankine Cycle (Steam Engine) Schematic

The nuclear-fueled Rankine cycle merely changes the method of generating the steam in the steam generator, and the arguments outlined above for the nuclear Brayton cycle, as well as those for the petroleum-fueled Rankine cycle, are applicable equally to this propulsion system.

5.2.1.3.6 Stirling Cycle

The Stirling thermodynamic cycle (Figure 5-23) approaches the Carnot cycle, thus it operates at the highest possible efficiency of a heat engine operating between two temperature limits. It consists of two constant volume processes joined by two constant temperature processes - ideally heat is added to the working fluid at one constant temperature from the

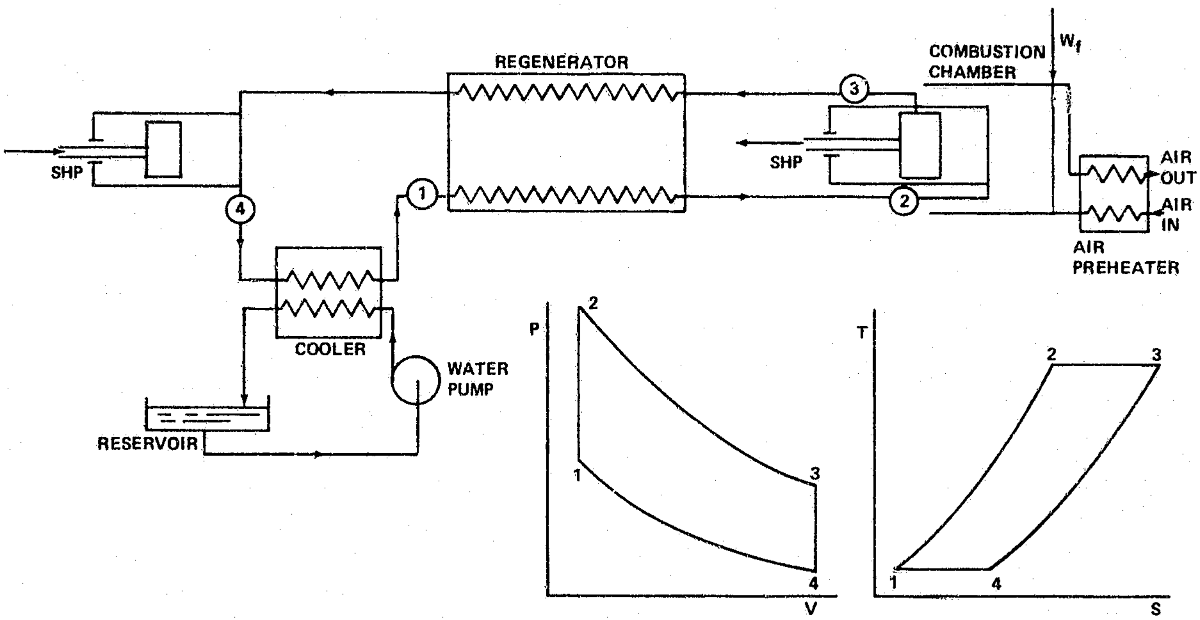


Figure 5–23. Stirling Cycle Schematic Diagram and Thermodynamic States

source (2 to 3, Figure 5-23) and rejected at a single lower temperature to the sink (4 to 1, Figure 5-23). To avoid heat exchange between the working fluid and the source or sink at intermediate temperatures, the constant volume processes are executed with the aid of a regenerator, a series of heat reservoirs not supplied with energy from any outside source. The gas is cooled from the higher to the lower temperature in one constant volume process, 3 to 4, by successive contact with parts of the regenerator, which are at temperatures ranging from that at the source to that at the sink; it is heated in the other constant volume process, 1 to 2, by contact with the same parts in reverse order. The Stirling cycle is an external combustion engine, and the combustor burns any type of fuel. Inherently, the Stirling engine has high efficiency, reflected in its low SFC (Table 5-I).

To attain competitive specific outputs, it must handle large quantities of working fluid, and this is accomplished by maintaining a high mean pressure in the working spaces. State-of-the-art technology of Stirling engines is confined to relatively small shaft horsepower machines.

5.2.1.4 Performance and Weight Trend Data

Propulsion system specific weight trends (powerplant weight divided by shaft horsepower) are plotted in Figure 5-24 as a function of calendar year. Otto cycle trends were established using data from References 41 and 42, although weight data for later years were available only for small piston engines (upper boundary of the trend data). Potential weight trends for large piston engines were estimated, as indicated by the dotted lower boundary of the trend data. Aircraft Diesel engine data points from Reference 41 are plotted in Figure 5-24, falling generally within the bounds of Otto engine data, although previous discussion indicates that the comparable Diesel engine should be somewhat larger and heavier. Aircraft Diesel engine state-of-the-art has been without improvement since 1949. Aircraft gas turbine technology (Brayton cycle) has improved over the same period of time, to the extent that large engines today offer a specific weight ratio of 0.15 lb/shp (.07 kg/shp) and smaller engines offer a specific weight of 0.25 lb/shp (.11 kg/shp).

Nuclear-fueled Brayton cycle weight trends are also illustrated in Figure 5-24 with key data points based upon reactor weights from References 43 and 44 added to the gas turbine weights in the figure. Aircraft Rankine cycle weight data (petroleum fueled) is limited to small engines, exemplified by Reference 45, and indicated by the single data point. Nuclear fueled Rankine cycle weight data is developed in a manner similar to the nuclear-fueled Brayton cycle powerplant, by adding the reactor weight to that of the petroleum-fueled Rankine cycle. Finally, Stirling cycle engine weight is represented by a single data point based upon Reference 46.

Specific fuel consumption trends are plotted in Figure 5-25 as a function of shaft power, expressed as a percentage of rated engine power. The Otto cycle SFC is reasonably flat over a wide range of engine part power conditions. The higher compression and firing pressures of the compression-ignition Diesel engine result in a better thermal efficiency than the Otto cycle and are reflected in an improved SFC. Just as the technology advances in Brayton cycle turbine-inlet temperatures have resulted in specific horsepower and engine weight improvements, so technology advances in compressor pressure ratios have contributed to improvement in SFC. Brayton cycle

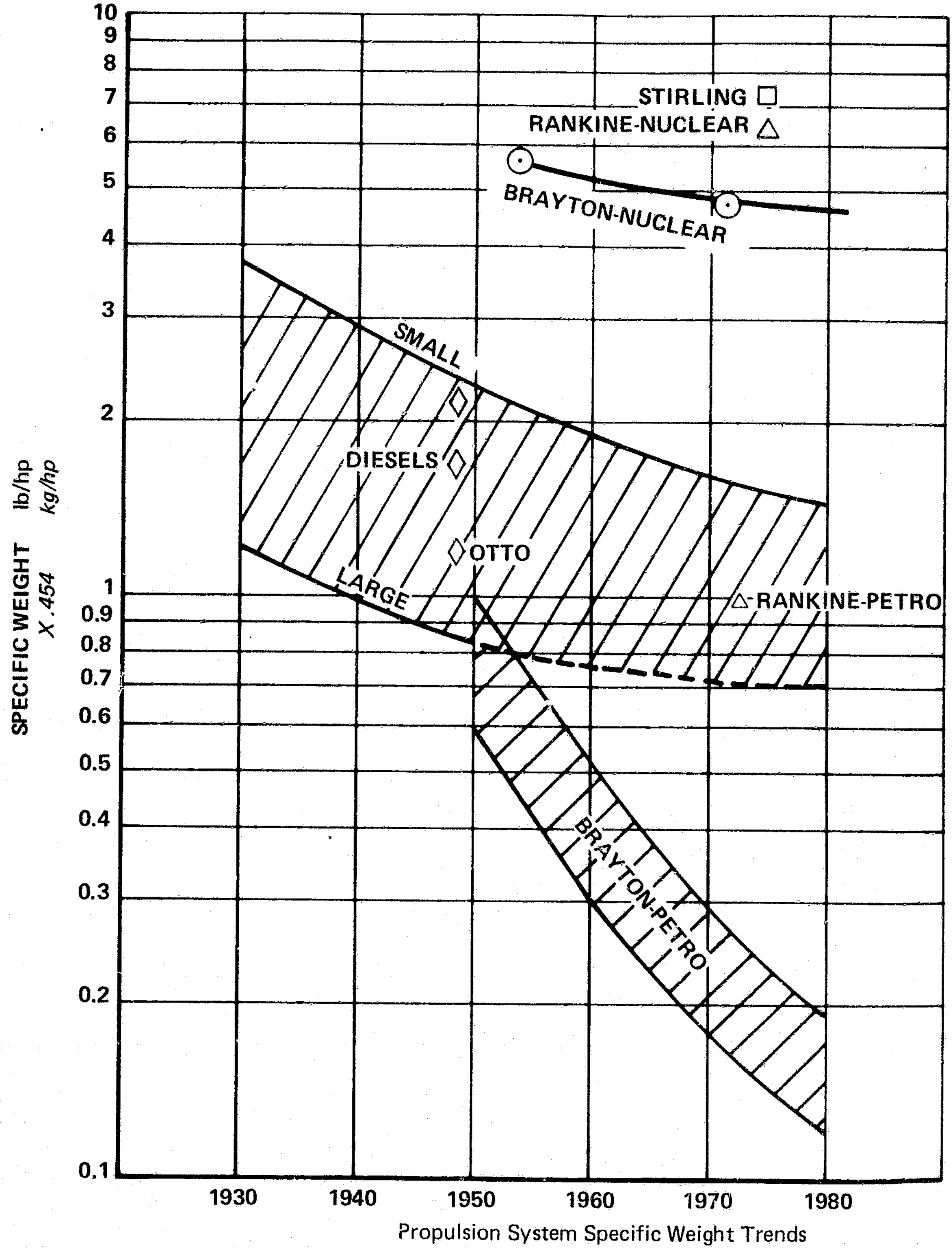


Figure 5–24. Engine Specific Weight Trends

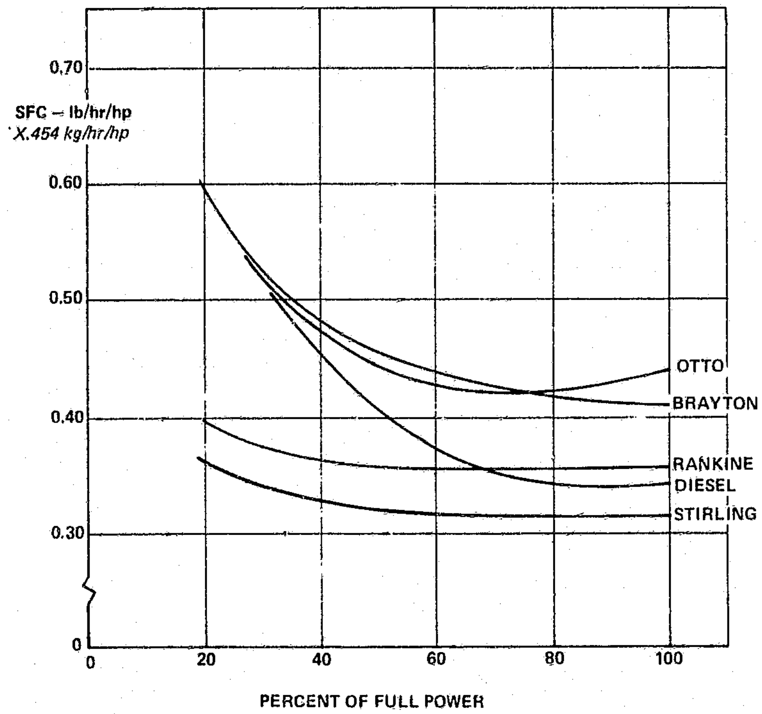


Figure 5–25. Specific Fuel Consumption Trends

shaft horsepower SFC's now approach .4 lb/hr/shp (.18 kg/hr/shp) for relatively large engines. Using a condensable vapor, such as water, as the working fluid reduces the large negative work of the other engine cycles, minimizes the impact of irreversibility, and so improves the network of the cycle. Consequently, the Rankine cycle thermal efficiency is quite high. Power output of the Rankine cycle is directly related to the circulating flow rate of the water/steam, and the steam generator maintains temperature and pressure under control of the governor, so the part-power characteristic of the Rankine cycle is extremely flat. The Stirling cycle operates at the highest possible thermal efficiency of a heat engine operating between two temperature limits, reflected in the low SFC plotted in the figure, which changes very little down to relatively low part-power conditions.

5.2.1.5 Engine Exhaust Composition

Exhaust-emission data are available principally for the engines of road vehicles. Because of the variety of Otto and Diesel engines in production, it is difficult to establish typical, accurate exhaust-emission figures. In the case of Brayton, Rankine, and Stirling cycle engines, few are in vehicles. However, Figure 5-26 is presented to illustrate graphically

the relative amount of emissions (data from Reference 47). The order in which the engines are arranged is indicative of the amount of emissions, from most to least - i.e., Otto, Diesel, Brayton, Rankine, and Stirling cycles.

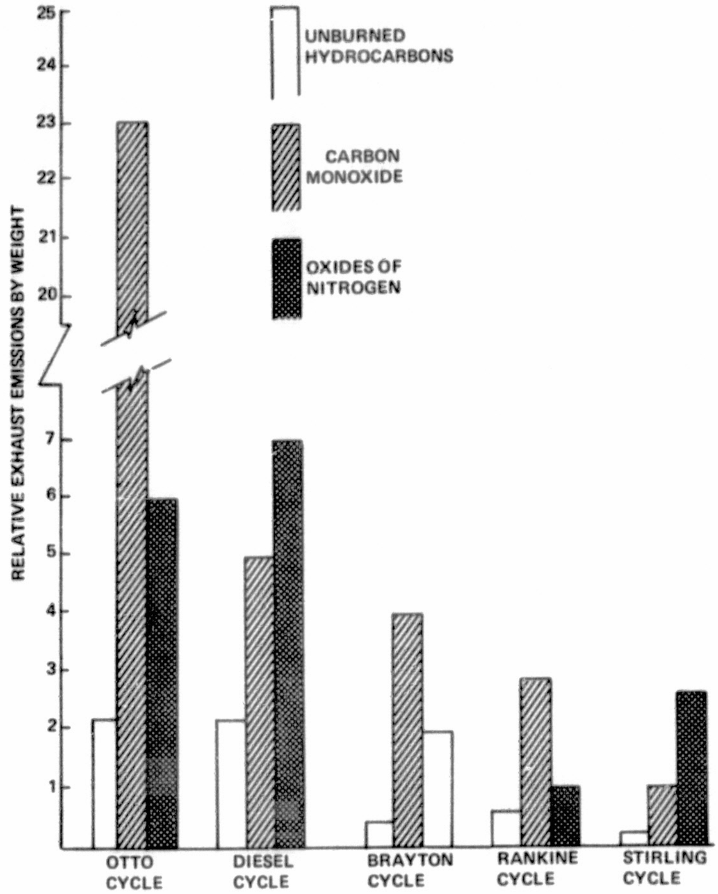


Figure 5–26. Engine Exhaust Emission Data

5.2.1.6 Engine Cycle Selection

5.2.1.6.1 Methodology

The engine cycle for the airship shaft power system was selected on the basis of the criteria listed in Table 5-II. The weighting factors for each of the evaluation criteria, to determine their importance in relationship to each other for purposes of quantifying the comparative evaluation, are also developed in Table 5-II. Each evaluation criterion is compared with every other one in turn, with the criterion of greater importance (in the opinion of the evaluator) being scored 1 and the criterion of lesser importance being scored 0. The weighting factors are the resulting sums.

Table 5—II. Engine Cycle Selection Criteria

PARAMETERS	SCORES							WEIGHTING FACTORS
1. FUEL CONSUMPTION (CRUISE SFC)	1111111							7
2. PROPULSION SYSTEM WEIGHT/SHP	0	110111						5
3. TECHNICAL RISK OF DEVELOPMENT STATE-OF-THE-ART AVAILABILITY	0	0	10111					4
4. TYPE OF FUEL AVAILABILITY COST	0	0	0	0011				2
5. AIRSHIP DESIGN FACTORS COMPLEXITY – SUBSYSTEMS, COMPONENTS PROPULSION RELIABILITY & MAINTAINABILITY IMPACT ON AIRSHIP DESIGN SAFETY	0	1	1	1	111			6
6. EXHAUST EMISSIONS POLLUTANTS WATER HEAT	0	0	0	1	0	11		3
7. PROPULSION SYSTEM VOLUME/SHP	0	0	0	0	0	0	1	1
8. POWER LAPSE RATE (ALTITUDE)	0	0	0	0	0	0	1	1

Scoring of the majority of the evaluation criteria was based upon level of technology, according to the numerical scores listed below:

Score	Level of Technology
5	Excellent - near optimum technology
4	Good - exceeds minimum requirements
3	Adequate - generally meets minimum requirements
2	Weak - does not meet minimum requirements
1	Poor - omissions in a major area
0	Inadequate - deficient in major areas

Technical risk of development and fuel availability and cost were evaluated on the basis of technical risk scoring, according to the following numerical scores:

Score	Technical Risk
5	Substantially "0" risk - production aircraft technology which needs no modification
4	Insignificant - similar to production technology, only minor changes required
3	Low - uses proven improvements from component programs
2	Moderate - developmental areas within the state-of-the-art
1	High - minor breakthroughs required, probability of unforeseen development problems
0	Critical - requires major breakthroughs

5.2.1.6.2 Comparative Evaluation and Selection

The comparative evaluations are quantified in Table 5-III. Total possible score for a propulsion system is the sum of the weighting factors (29) multiplied by the highest score (5 for highest level of technology or lowest technical risk), 29 x 5 = 145.

Comparative scores for fuel consumption, specific weight, and emissions reflect the data plotted previously. Scores for technical risk of development are consistent with the "off the shelf" production status of the gas turbine powerplant, the minor risk of development for Otto and Diesel engines, the moderate risk inherent in the Rankine cycle, the high risk of the Stirling cycle, and the critical risk of nuclear-powerplant development. Fuel availability and cost also were evaluated on a risk basis, relative to the availability and refinement required. Judged on this basis, slight differences in risk were attributed to the difference between refined gasoline for the Otto and Stirling engines and the cruder petroleum grades used in the Diesel, Brayton, and Rankine engines, but the nuclear fuel availability and cost was assumed to be a moderate risk.

Table 5—III. Comparative Evaluation of Airship Engine Cycles

PROPULSION SYSTEM SELECTION CRITERIA	WEIGHTING FACTOR	ENGINE CYCLE: SCORING (0 to 5) X WEIGHTING FACTOR						
		OTTO	DIESEL	BRAYTON-PETRO	BRAYTON-NUCLEAR	RANKINE-PETRO	RANKINE-NUCLEAR	STIRLING
FUEL CONSUMPTION (CRUISE SFC)	7	14	21	14	35	21	35	28
PROPULSION SYSTEM WEIGHT/SHP	5	20	15	25	10	15	5	0
TECHNICAL RISK OF DEVELOPMENT STATE-OF-THE-ART AVAILABILITY	4	16	16	20	0	8	0	4
TYPE OF FUEL AVAILABILITY COST	2	8	10	10	4	10	4	8
AIRSHIP DESIGN FACTORS COMPLEXITY-SUBSYSTEMS/COMPONENTS PROPULSION RELIABILITY & MAINTAINABILITY IMPACT ON AIRSHIP DESIGN SAFETY	6	30	30	30	12	18	6	24
EXHAUST EMISSIONS POLLUTANTS WATER HEAT	3	0	3	6	15	9	15	12
PROPULSION SYSTEM VOLUME/SHP	1	4	3	5	0	2	0	1
POWER LAPSE RATE	1	5	5	4	4	5	5	5
TOTAL	29*	97	103	114	80	88	70	82

*TOTAL POSSIBLE SCORE = 29 x 5 = 145

Comparative scores for the airship design factors criterion are based upon the complexity of the propulsion system in terms of numbers of subsystems and components, and its impact on the airship design as well as airship reliability and maintainability factors, so these scores directly reflect engine complexity. Propulsion system safety also is taken into account, specifically in the nuclear-fueled powerplants.

Comparative scores in Table 5-3 lead to the selection of the petroleum-fueled Brayton cycle powerplant for the airship, primarily on the basis of superior engine weight and minimum development risk. The selection is dependent upon mission length to a certain extent, since longer missions tend to favor the low-SFC engine even if its specific weight is larger. The mission length which results in equal engine + fuel weight for two different powerplants (1 and 2) can be expressed as follows:

$$\Theta = \frac{\rho_1 - \rho_2}{SFC_2 - SFC_1}$$

where: Θ = mission length, hours

ρ = engine specific weight, lb/shp (kg/shp)

SFC = specific fuel consumption, lb/hr/shp (kg/hr/shp)

The above discussions have been related to engines developed for aircraft use, i.e. light weight engines. However, if long endurance missions (3 days or more) would be predominating then heavier non-aviation engines such as marine diesels, may be preferred. The lower fuel consumption will more than pay for the weight penalty. Airworthiness certification of such engines will be required.

In the instance of extremely long endurance/range missions, the nuclear power Brayton cycle becomes of primary interest despite the high risk of development, the risk in availability and cost of fuel, and the complexity and safety considerations of the power plant.

5.2.2 Buoyant Fluid Trade-Off

5.2.2.1 Summary and Conclusions

The efficient lifting gases are hydrogen and helium. Hydrogen, with its better lifting capability is relatively inexpensive with an inexhaustable supply. However, its flammability may possibly forever prevent general usage of this gas Helium is very expensive and the supply, although adequate for the foreseeable future airships, may have a long range future availability problem.[48] Therefore, other buoyant fluids as shown in Figure 5-27, must be considered for application in the future airship.

Helium was selected as the gas to be considered in this preliminary design and analysis study because of its safety, availability, and ease of system design. However, in the future, detailed studies should be made of alternatives, such as steam systems (gas is low cost, but the system weight/cost may be prohibitive) and fail-safe hydrogen (containment) systems.

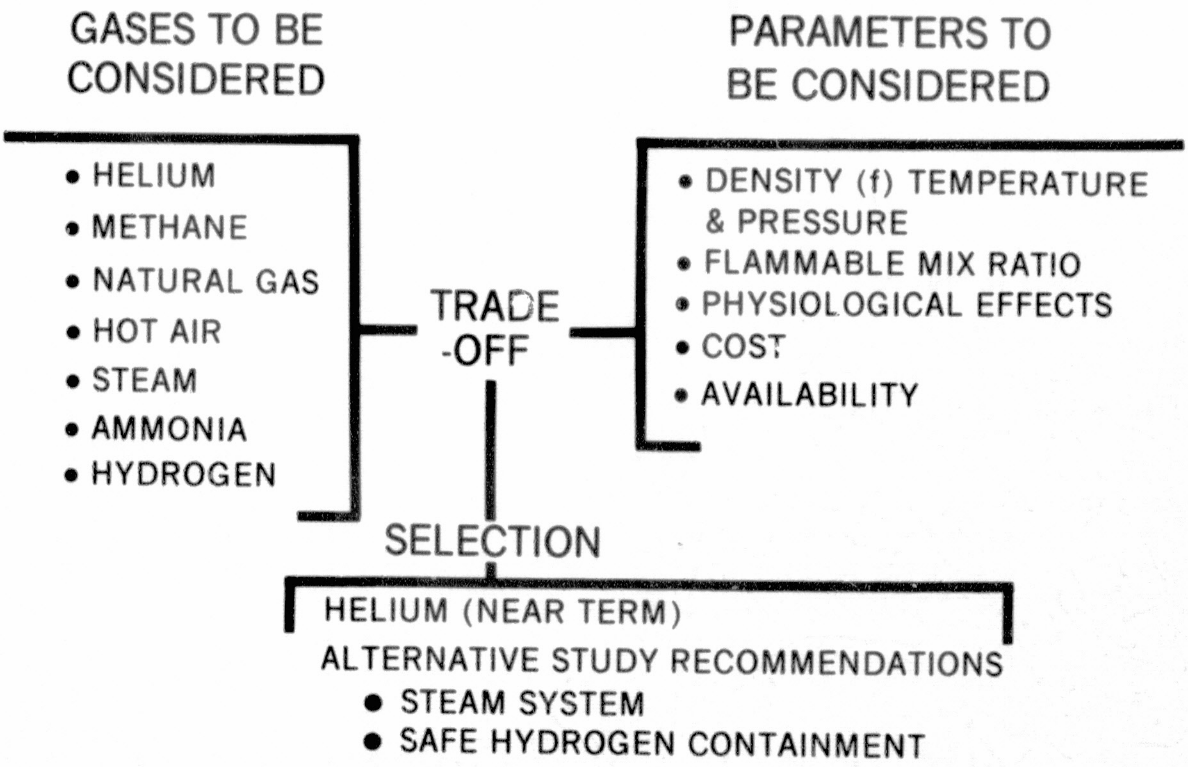


Figure 5–27. Buoyant Fluid Trade-Off

5.2.2.2 Buoyant Fluid Characteristics

The characteristics of the candidate buoyant fluids are summarized in Table 5-IV.[50, 51, 53]

5.2.2.2.1 Buoyant Lift Capability

An examination of the characteristics of various buoyant fluids to be used as lifting gas reveals that there may be only three fluids which can supply sufficient lift for a fully buoyant modern airship: hydrogen, helium and steam.

TABLE 5-IV BUOYANT FLUIDS, CHARACTERISTICS AND COSTS (UNDERLINED DIGITS INDICATE SUPERIORITY IN SHOWN PARAMETER)

Table 5–IV. Buoyant Fluids. Properties and Characteristics

BUOYANT FLUID	FLAMMABILITY IN AIR % BY VOLUME LOWER LIMIT	FLAMMABILITY IN AIR % BY VOLUME UPPER LIMIT	DENSITY AT ISA SL 100% PURITY lb/ft^3 *kg/m^3*	LIFT OF MASS CAPABILITY AT ISA SL 100% PURITY $lb/10^3\ ft^3$ *$kg/10^3\ m^3$*	TYPICAL COST FOR GAS 1975 U.S. $\$/10^3\ ft^3$ *1975 U.S. $\$/10^3\ m^3$*	TYPICAL COST FOR EACH UNIT OF LIFT ¢/lb *¢/kg*
HYDROGEN H_2	4.0	74.2	.00532 *.08526*	71 *1,140*	4.10 *144.80*	5.8 *12.7*
HELIUM He	0	0	.01057 *.16930*	66 *1,056*	47.80 *1,687.85*	72.4 *159.7*
STEAM 212°F *100°C*	0	0	.03731 *.59759*	39 *629*	.10 *3.50*	.3 *.6*
METHANE CH_4	5.0	15.0	.04237 *.67852*	34 *547*	2.00 *70.60*	5.9 *13.0*
AMMONIA NH_3	16.0	27.0	.04498 *.72035*	32 *505*	5.50 *194.20*	17.2 *37.9*
NATURAL GAS (TYPICAL)	4.5	14.5	.04996 *.80004*	27 *425*	1.30 *45.90*	4.8 *10.6*
AIR 248°F *120°C*	0	0	.05607 *.89790*	20 *327*	2.15 *75.90*	10.8 *23.7*
212°F *100°C*	0	0	.05908 *.94603*	17 *279*	1.70 *60.00*	10.0 *22.0*
59°F *15°C*	0	0	.07650 *1.22508*	0 *0*	0 *0*	— —

Figure 5-28 illustrates the lift capability of the buoyant fluids for a hypothetical 16 x 10^6 ft (453 x $10^3 m^3$) airship. The example design gross weight using helium or hydrogen could be approximately 1,000,000 lbs (454,000 kg.) of which, depending on EW/GW ratio, 400,000 to 600,000 lbs (181,440 to 272,160 kg.) would be available for useful lift (mission fuel and payload).

However, the other gases, methane, ammonia, and natural gas, as well as hot air, will probably only be able to lift the empty weight. The remaining gas, steam, may be of interest (very low cost) if a total system concept can be developed with a low EW/GW ratio. Hot air, in the range of 300°-400°C might also be of interest, but the materials limitations would probably preclude a low EW/GW ratio.

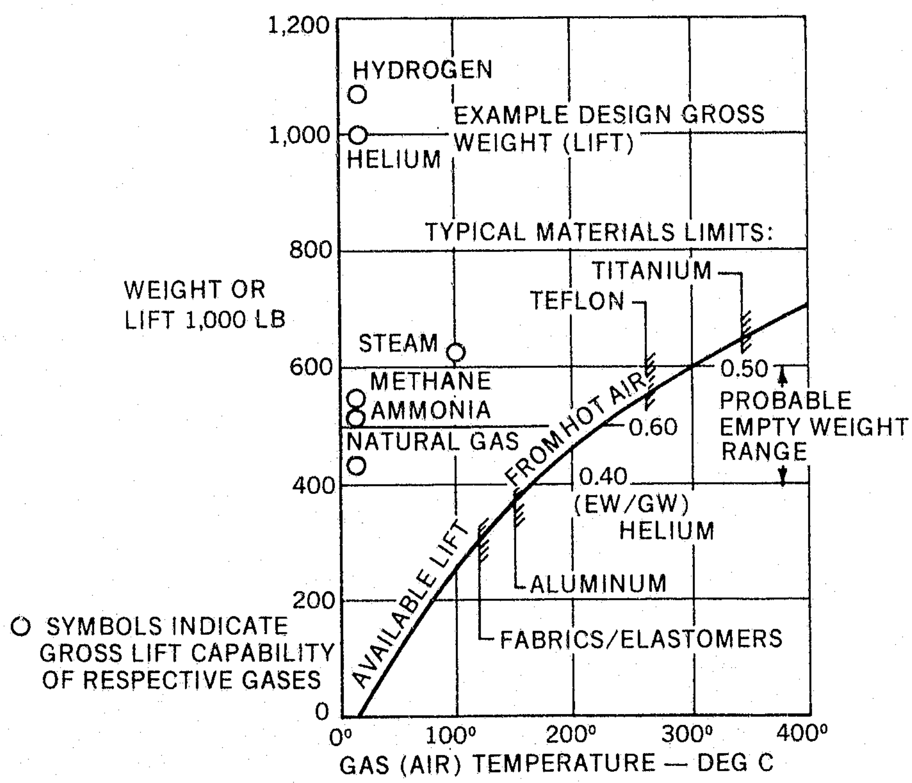


Figure 5–28. Comparison of Buoyant Fluid Lift Capability (Airship Nominal Gas Volume = 16 x 10^6 FT^3 (453 x 10^3 m^3))

5.2.2.2.2 Flammability

Of the candidate buoyant fluids, only helium, steam, and hot air are inflammable. Although at this time, a hydrogen (or other inflammable gas) filled airship is not likely to be acceptable, there is some possibility, with advanced technology, of developing a fail-safe containment system.

5.2.2.2.3 Physiological Effects

Hydrogen and helium are nontoxic but act as an asphyxiant by displacing the necessary amount of oxygen in the air to support life. Methane is usually not considered a toxic gas, but the physiologic effect is that of an asphyxiant when present in high concentrations. Coal miners frequently breathe air containing 9% of methane without any apparent effect. Natural gas is very much like methane, since methane constitutes about 90% of the natural gas.[51]

The corrosive action of ammonia on humans is another reason for making this gas less attractive for use in an airship. It is of course unlikely that an individual would unknowingly become overexposed. The pungent odor of ammonia provides ample warning of its presence. Concentrations in the range of 20 - 50 p.p.m. are detectable.[51] That the corrosive characteristics of ammonia must be considered when selecting construction material, goes without saying.

The physiological effect of steam and hot air is limited to the elevated temperature which can cause burns if, through accident, humans are exposed.

5.2.2.2.4 Costs

Table 5-IV also shows typical costs for the various buoyant fluids.[56] The cost for steam considers a steam generation plant on the ground with an efficiency typical for todays steam plants. Methods and costs to maintain the steam in an airship will be discussed in paragraph 5.2.2.3, Candidate Buoyant Fluids. The cost of hot air is based upon a modern hot air furnace.

5.2.2.3 Candidate Buoyant Fluids

Helium and steam emerge as safe candidate buoyant fluids. Both are non-flammable and, of course, helium has acceptable lift. Steam, however is marginal in lift capability. Steam has, in addition, a very attractive cost as seen in Table 5-IV. It should be noted, however, that the containment and temperature sustaining systems for steam as a lifting gas require research and development effects. Hydrogen should remain as

C-3

a future candidate buoyant fluid providing that a fail-safe containment system can be developed.

5.2.2.3.1 Helium

The known world supply of helium to cover all foreseeable needs, in addition to modern airships, should be sufficient for the next 10 - 15 years, providing there will not be an explosive growth in number of airships.[55] Although a modern gas cell for an airship can be designed with a permeability of $.5 \ell/m^2$ 24 hr., present aerostats experience a leakage rate of 60% of the gas volume per year, due to seams, attachments, stretching, etc. Thus, an airship uses helium dissipatively to a large extent without any possibility for reclamation and reuse of the leaking helium. The cost of helium including the cost of leakage is plotted in Figure 5-29 and discussed in paragraph 5.2.2.3.2.

The U.S. Bureau of Mines estimates that by 1980-90 helium supplies will be obtained from helium stored under the conservation program, from lower helium content fuel gas streams, or from isolated small fields where the helium-bearing natural gas has little or no value as fuel. Sharp price increases can hence be expected. The future of the airship, if other considerations so permit, will thus require the development of systems to use steam or a flammable gas such as hydrogen under uncompromising safety conditions; with steam as prime candidate from a cost point of view.

Helium is presently extracted in the U.S.A., Canada, France, USSR and other Eastern European countries.[55]

5.2.2.3.2 Steam

An airship for steam as buoyant fluid requires a special design of the gas container to minimize the heat losses. Here new ideas and development will be required to provide lightweight insulation concepts. One such concept has been suggested and patented by H.E.R. Papst, West Germany.[52] Consisting of a double wall envelope filled with a heated inert gas as insulation and with folding foils with reflective coating to reflect the radiating heat back to the container, it seems to be feasible to limit the heat loss to less than 10 BTU/ft^2h (27 $Kcal/m^2$ h). (See Figure 5-30)

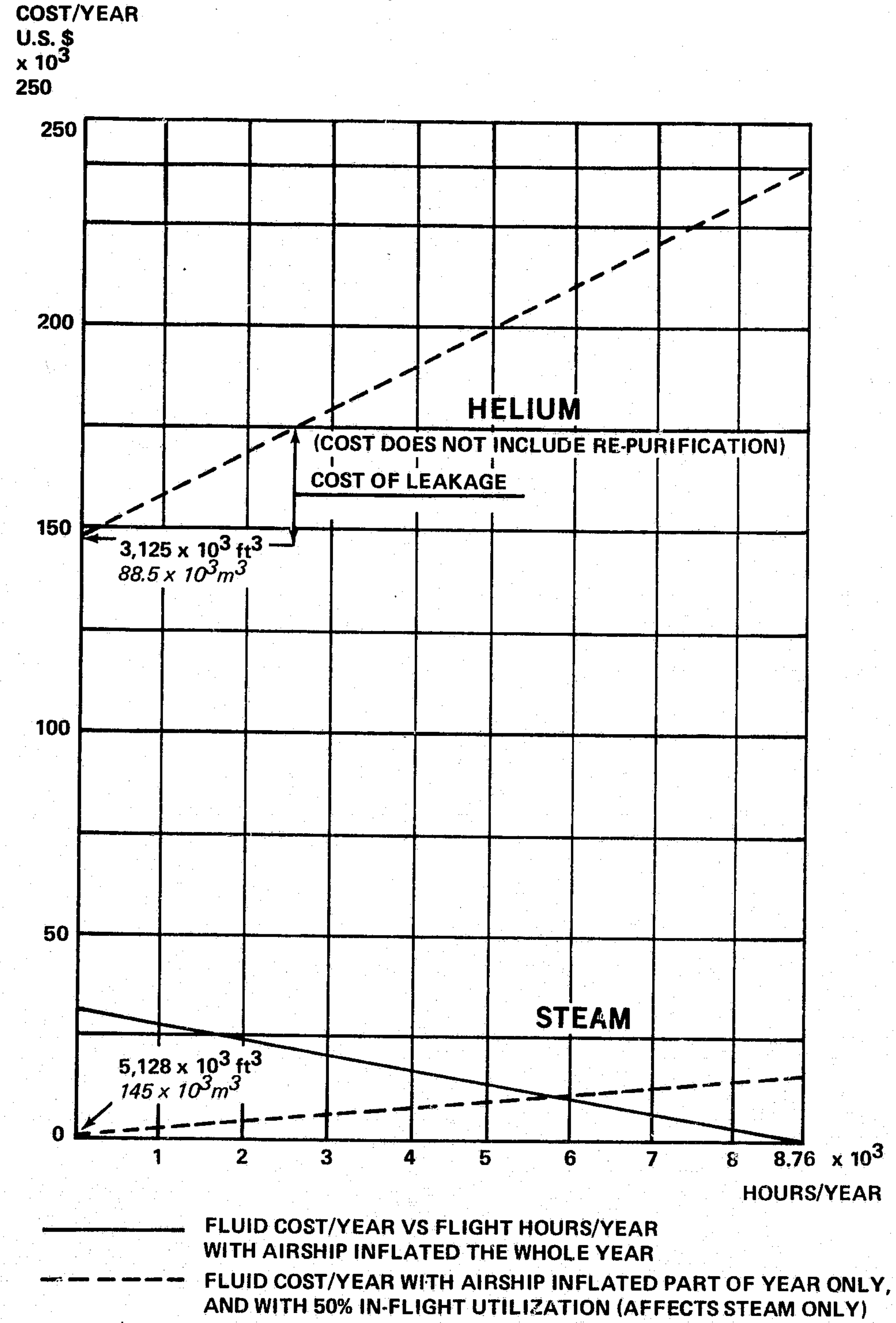


Figure 5–29. Buoyant Fluid Cost Per Year for Helium and Steam (Airship Static Gross Lift of 200,000 LB/90,720 KG)

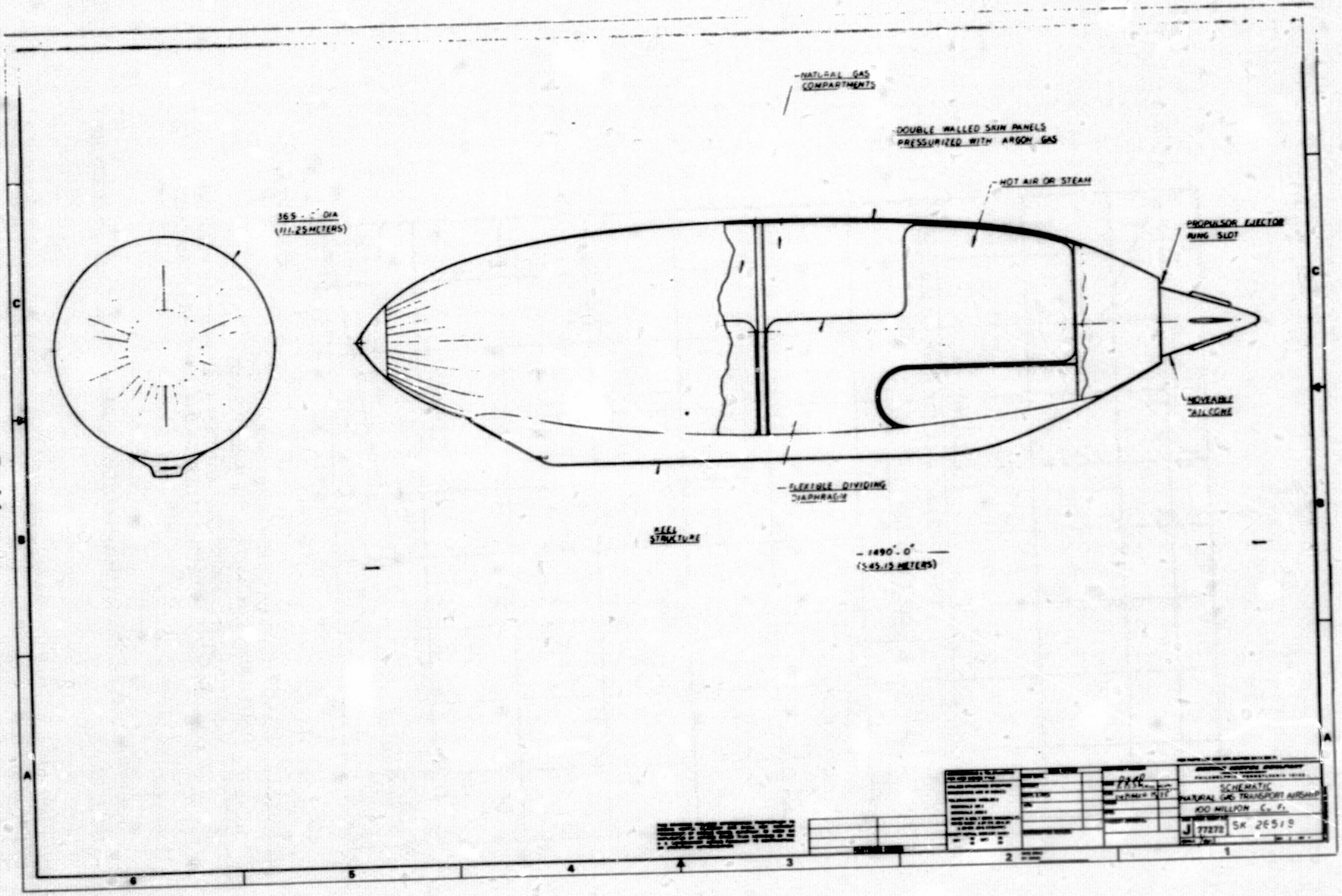


Figure 5–30. Schematic of Natural Gas Transport Airship (Papst Concept)

Inflation of the airship will be made from a steam generator. Present state-of-the-art can produce compact steam generators of sufficient large capacity to provide short inflation times.

The most probable power plant to propel a modern airship is a turboprop engine. The heat content of the exhaust gases of the engine size required to propel an airship of a certain volume, at such a low speed as 50 knots (25.7m/s) is about four times more than required to replace the heat losses of about 10 BTU/ft^2h (27 Kcal/m^2 h) from steam of the same volume.

When not in flight, on-board auxiliary heat has to be supplied; if not on board, a steam generating plant must be available.

Buoyant fluid costs for helium and steam are shown in Figure 5-29. They have been developed for an airship of approximately 200,000 lb (90,720 kg) of static gross lift. Two cases are shown: (a) the airship remains inflated the whole year as shown on the abscissa (solid lines); (b) the airship is inflated only the hours shown on the abscissa per year (broken lines) with the airship in-flight conditions 50% of the time. (The in-flight condition is important only for the steam airship from a cost point of view.)

With buoyant fluid prices as shown in Table 5-IV, it will cost to inflate a helium airship of 3,125 x $10^3$$ft^3$ (88.5 x $10^3$$m^3$) volume $149,375. With 60% leakage over a year, the total cost amounts to $239,000 per year. Correspondingly the steam for a 5,128 x $10^3$$ft^3$ (145 x $10^3$$m^3$) volume airship will cost $513. The leakage cost will be $308 per year.

In addition to the quoted costs for steam, the cost for maintaining the steam must be considered. In flight there are no such costs. The exhaust gas heat is used. With shut-down engines, it will cost $3.47 per hour to replace the heat losses.

In case (a) with the airship inflated all the time, the helium cost per year is 8.6 times higher than the steam cost at 1,000 FH per year. At 6,000 FH per year, the helium is 23 times greater.

Case (b) assumes that the airship is inflated only a certain time of the year with few flights spread over the year. It will be more economical to deflate the helium into a tank to prevent losses due to leakage, and more economical to generate new steam than to maintain the inflated one. Under these conditions and an inflation period of 1,000 hours with 500 hours in flight, the helium cost is 70 times greater than the

steam cost. With 4,000 hours inflation time a year, the helium cost is 11 times higher.

5.2.2.4 Recommendations

Helium is recommended as the prime candidate for the buoyant fluid for this design study. Experience is at hand and it will offer least design problems. Helium will, however, increase considerably in price and eventually become unavailable in the huge quantities as required by airships.

Therefore, it is also recommended that development of systems for other buoyant fluids is started in the early years of a revived airship. Such a buoyant system must be completely safe and not impose unacceptable weight and cost penalties. Steam seems to be a promising candidate but with many challenging technical problems. Because of all the unknowns, a parallel task to develop a fail-safe containment system for hydrogen should be undertaken.

5.2.3 Materials/Structures Concept Trade-Off

5.2.3.1 Summary and Conclusion

Structures and materials for both rigid and non-rigid buoyant and partially buoyant concepts were analyzed. For non-rigid concepts a triaxial weave KEVLAR 29 laminate (with polyurethane and Tedlar films) was selected for the primary envelope. This fabric construction provides exceptional strength/weight characteristics, excellent permeability, and resistance to ultraviolet radiation and aging. An envelope weight reduction of 3:1 or more can be achieved when compared to the past typical cotton/neoprene types.

For rigid concepts, an advanced composite geodetic construction was selected for the preliminary design and parametric analysis. This concept uses triaxial and biaxial weave KEVLAR laminates as well as KEVLAR/Epoxy combinations to achieve a hull weight reduction of about 25 percent with respect to typical ZRS-4 Akron weights.

5.2.3.2 Non-Rigid Materials and Structures

The selection of specific materials for application to LTA construction must consider many factors. The first consideration must be the tensile stresses to which the material will be exposed. These can be accurately predicted from a static stress analysis of the end configuration and from dynamic analysis and wind tunnel tests on model structures. The hull fabric analysis must consider what part the material plays in the total structure. In non-rigid LTA's, the hull fabric provides all of the structural support and also serves as a permeability barrier. In any case, the overall size and performance; i.e., speed and maneuvering requirements are prime factors in determining the structural requirements. Further discussion and analysis of these aspects may be found in Appendix B.

In Appendix B, a number of candidate materials, were considered such as cotton, Nylon, Dacron, and KEVLAR in both two-ply biased and triaxial constructions. Based upon an overall evaluation of properties such as permeability and long term life with no flex fatigue coupled with its excellent physical properties and low weight, a coated triaxially woven fabric is considered to be an excellent candidate material construction for non-rigid envelopes.

In selection of coatings for hull fabrics, service life and service environment are prime considerations. In non-rigid LTA's, permeability to the lifting gas is an equally important consideration. Ease of application of the coatings to the fabric and to themselves or other coatings, must also be considered.

Polyurethane is rapidly evolving as the most versatile and reliable of currently available coatings in providing an optimum balance of the above properties. Its mechanical properties are unexcelled, and its permeability and weather resistance can be effectively augmented when required by application of a thin film of Tedlar.

Table 5-V describes candidate materials of the construction described above for non-rigid envelopes. Projected weight and strength data have been included for both dacron polyester and KEVLAR 29 yarns and are plotted in Figure 5-31. It is apparent from the curves that a significant weight savings can be realized with KEVLAR. Therefore, a triaxial weave KEVLAR 29 laminate (with polyurethane and Tedlar films) is selected for the non-rigid helium-inflated airship envelope.

5.2.3.3 Rigid Hull Structure and Materials

Since an adequate design and technology base for modern rigid airship structure design is not at hand, investigation of various structural/material concepts was undertaken using a typical 1930's technology rigid airship bay structure as a baseline. This 67.5 ft (20.6 m) long bay from a 6×10^6 cu.ft (172×10^3 m^3), 122 ft (37.2 m) diameter hull was drawn up using the loads data from Reference 13 and the ZRS-4 Akron structural details as a guide (Figures 5-32 and 5-33). A baseline typical 1930's bay weight breakdown was then calculated for correlation with similar data for the Akron. Six alternative 1975 state-of-the-art candidate concepts, were then evaluated primarily for weight trending factors, but also to determine possible design concepts for all vehicles under evaluation.

5.2.3.3.1 Candidate Rigid Structural Concepts

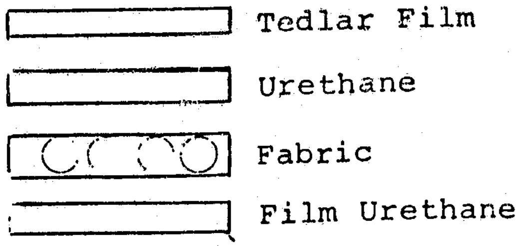
Candidate No. 1

This concept is identical to the baseline (Figures 5-32 and 5-33) except for use of advanced materials. Main structural girders were of either 2024-T3 or 7075-T6 in place of 17SRT. A cover of biaxial KEVLAR 29 laminate replaced the doped cotton fabric of 1930. All shear, flutter, and gas cell wires were replaced with KEVLAR 29 rope constructions. Gas cells are of biaxial KEVLAR laminates in accordance with selection of Appendix B.

Candidate No. 2

This candidate is also nearly identical to the baseline except for the substitution of composites as applicable. Main structural girders were of KEVLAR 49/Epoxy composite elements while other elements are as described for candidate No. 1.

Table 5–V. Triaxial Construction Candidates



Kevlar 29

Count*	Yarn**	Tensile (lb/in)	Weight (oz/yd^2) Film Urethane	Fabric	Urethane	Tedlar Film	Total
18.5 x 3	140/1	105	1.5	1.0	1.0	1.0	4.5
18.5 x 3	200/1	150	1.5	1.5	1.0	1.0	5.0
18.5 x 3	400/1	370	2.0	3.1	1.4	1.0	7.5
18.5 x 3	400/2	740	2.0	6.2	1.8	1.0	11.0
18.5 x 3	400/3	1100	2.5	9.3	2.2	1.0	15.0
18.5 x 3	1000/2	1850	4.0	15.4	3.6	1.0	24.0
10.0 x 3	1500/3	2250	4.2	18.8	4.0	1.0	28.0
10.0 x 3	1500/4	3000	6.0	25.0	4.5	1.0	36.5
18.5 x 3	1500/3	4150	7.0	34.7	5.3	1.0	48.0

Dacron Polyester

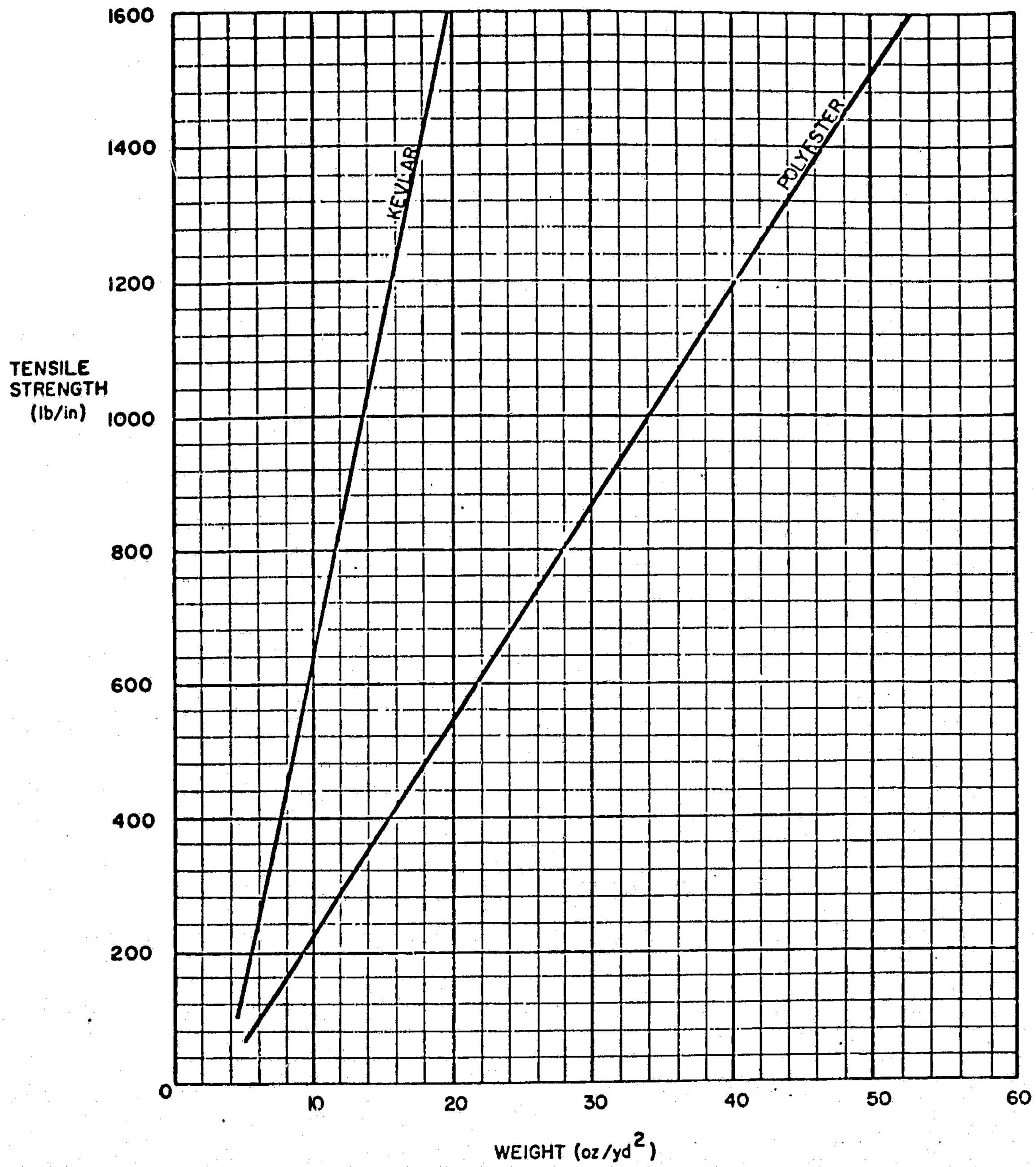
Count*	Yarn**	Tensile (lb/in)	Weight (oz/yd^2) Film Urethane	Fabric	Urethane	Tedlar Film	Total
18.5 x 3	200/1	65	1.5	1.5	1.0	1.0	5.0
18.5 x 3	400/1	130	2.0	3.1	1.4	1.0	7.5
18.5 x 3	400/2	260	2.0	6.2	1.8	1.0	11.0
18.5 x 3	400/3	390	2.5	9.3	2.2	1.0	15.0
18.5 x 3	1000/2	650	4.0	15.4	3.6	1.0	24.0
10.0 x 3	1500/3	790	4.2	18.8	4.0	1.0	28.0

* ends per inch x # of axes
** yarn denier/# of plies

NOTE:

It is anticipated that the minimum weight shown in the table represents the lightest composite weight that can readily be manufactured and handled using normal equipment and processes.

Conversion factors: 1 oz/yd^2 = 33.91 gm/m^2
1 lb/in = 1.75 n/cm



Conversion factors: 1 oz/yd^2 = 33.91 gm/m^2
1 lb/in = 1.75 n/cm

Figure 5–31. Triaxial Fabric Strength/Weight Characteristics

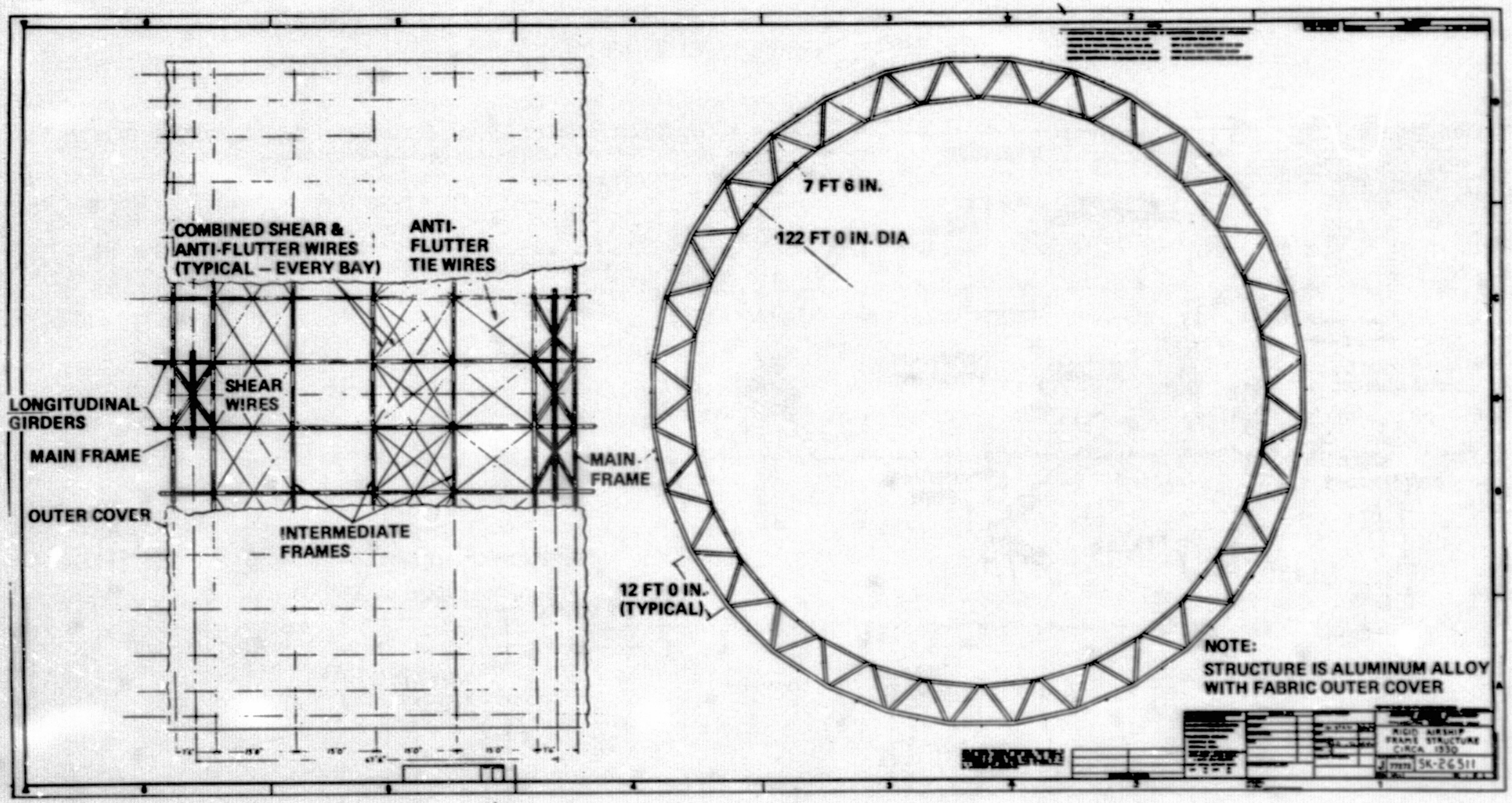


Figure 5–32. Rigid Airship Frame Structure – Circa 1930

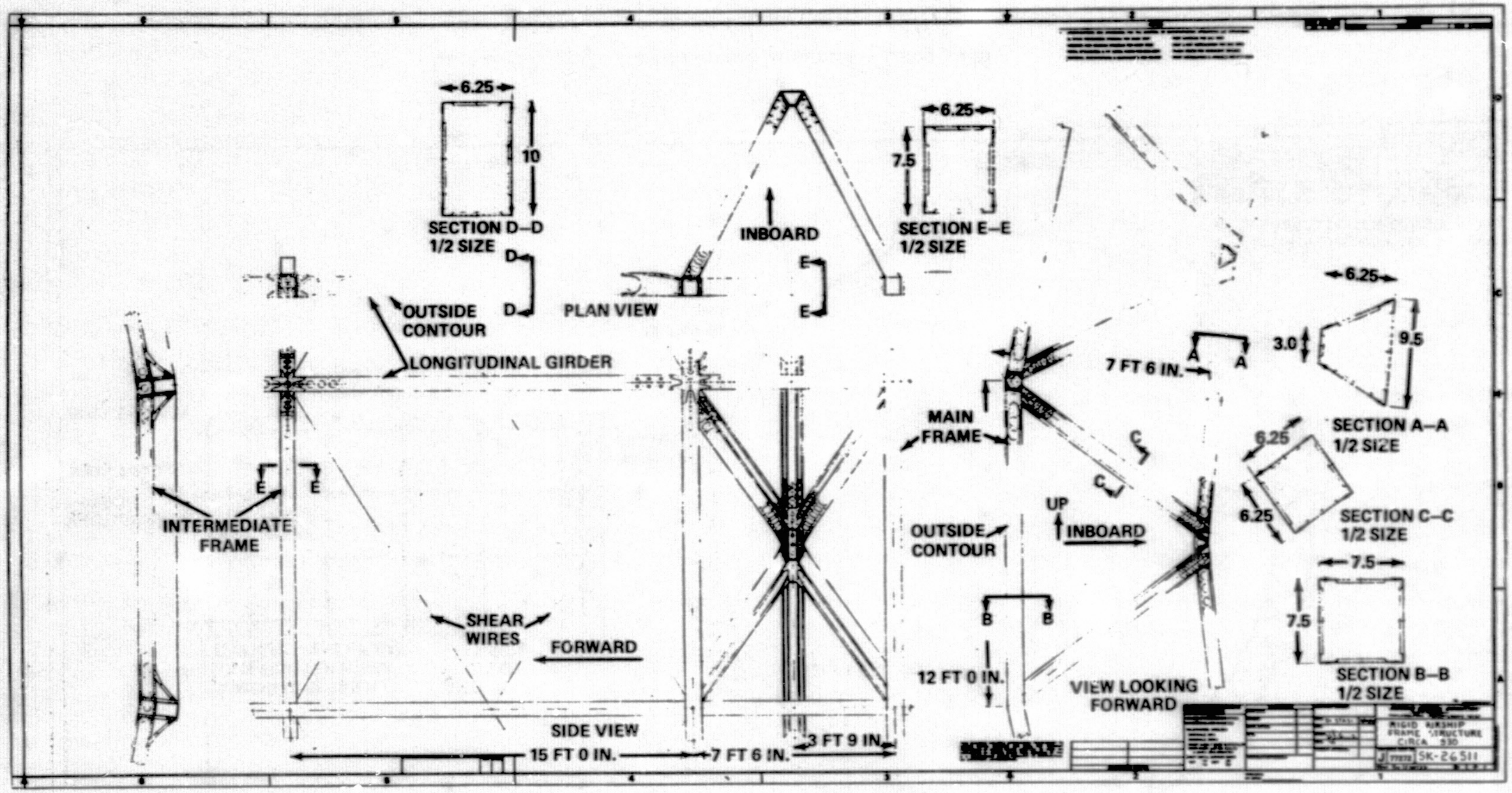


Figure 5–33. Rigid Airship Frame Structure – Circa 1930

Candidate No. 3

This pressure-rigid metalclad concept (Figure 5-34) is probably a very conservative approach. However, the necessity to recognize minimum gages from a manufacturing, handling and operational view point leads to very inefficient use of aluminum alloy materials. The overall applied loads do not generate local loads sufficient to dictate material gages. Further future work may be desirable in very large sizes to see if there may be a cross-over. However, on the surface, the very high strength of the KEVLAR/Epoxy materials would seem to militate against it.

Candidate No. 4

This concept, shown schematically in Figure 5-35 appears to take advantage of the characteristics of modern composites in a relatively simple construction. All materials are either KEVLAR laminates or KEVLAR/Epoxy forms.

Candidate No. 5

Figure 5-36 illustrates schematically a possible composite sandwich cover structural approach. The rigid outer shell has excellent damage tolerance aspects and the ability to carry both shear and axial loads. However, as in the metalclad concept, the local stresses are so low as to not require even the described 1 in. (25.4 mm) thick sandwich.

Candidate No. 6

Figure 5-37 illustrates an attempt at a conceptually simple structural approach - that of literally spinning the entire hull and its elements of various composite fiber materials. Perhaps, with further detailed design work, a variant of this concept might prove more efficient.

5.2.3.3.2 Selection of Structural Concept and Weight Analysis

Table 5-VI summarizes the weight calculations for the candidate concepts compared to the 1930's state-of-the-art. On the basis of lowest weight, selection could be made of either No. 1 using primarily modern aluminum alloys or No.'s 2 and 4 using all composite materials.

However, consideration of the relative simplicity of Concept No. 4 as opposed to the work-intensive aspects of the other two, leads to a selection of the Composite Geodetic Concept (using KEVLAR materials) as the most likely approach to rigid airship structural design. Based on the data from Table 5-VI, a weight trend constant of approximately 0.75 (applied to Akron weights) can be considered.

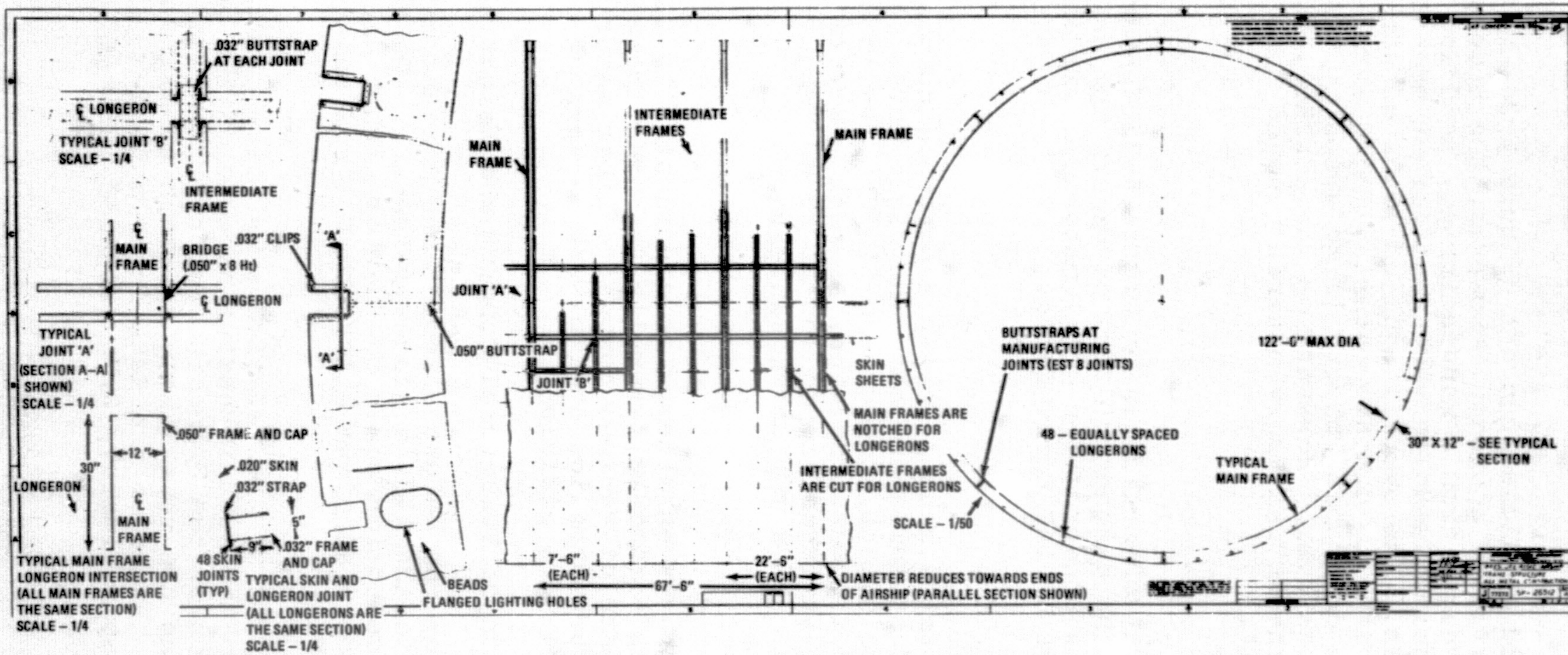


Figure 5–34. Pressure Rigid Airship Frame Structure (Candidate No. 3)

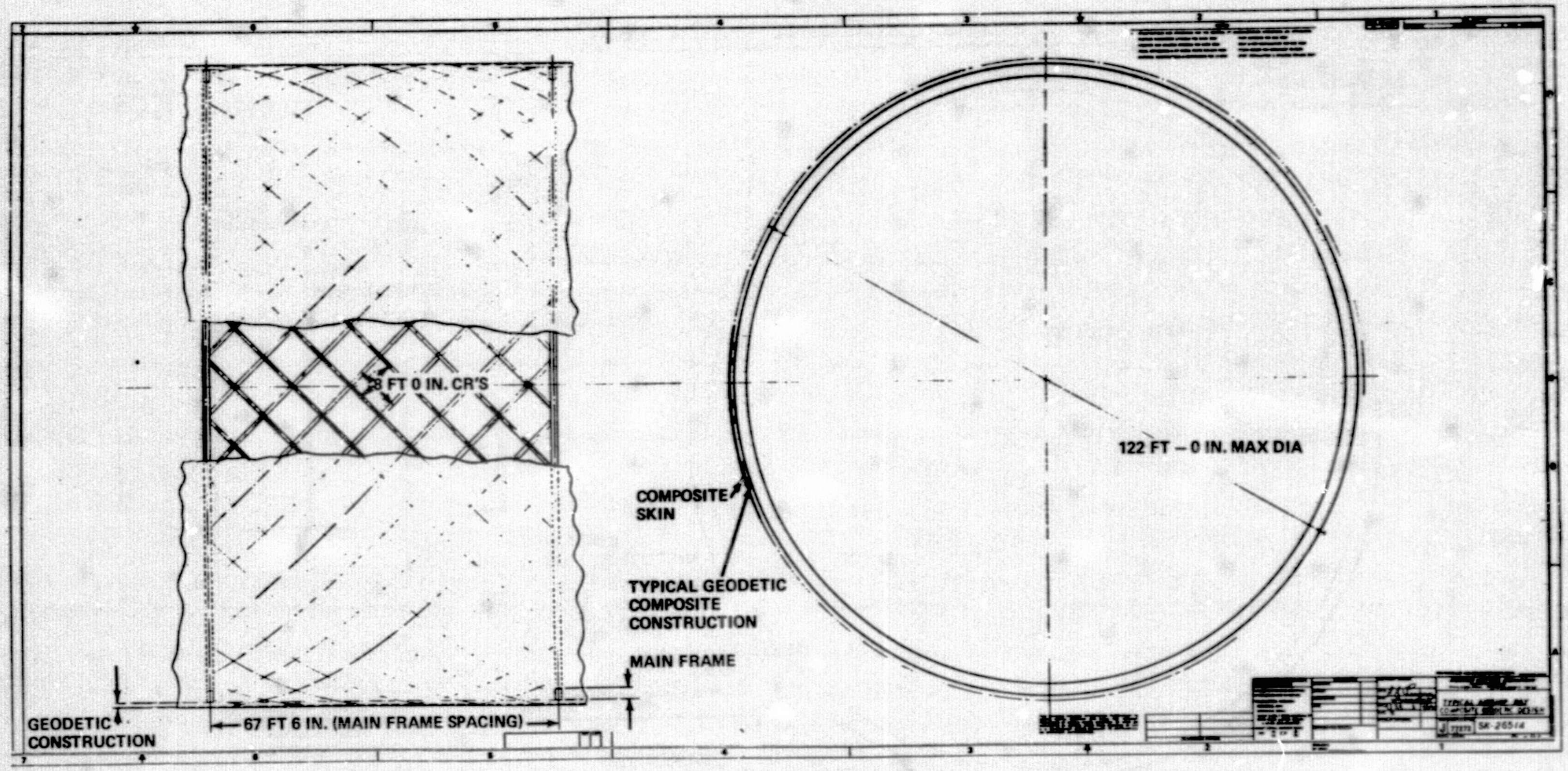


Figure 5–35. Composite Geodetic (Candidate No. 4)

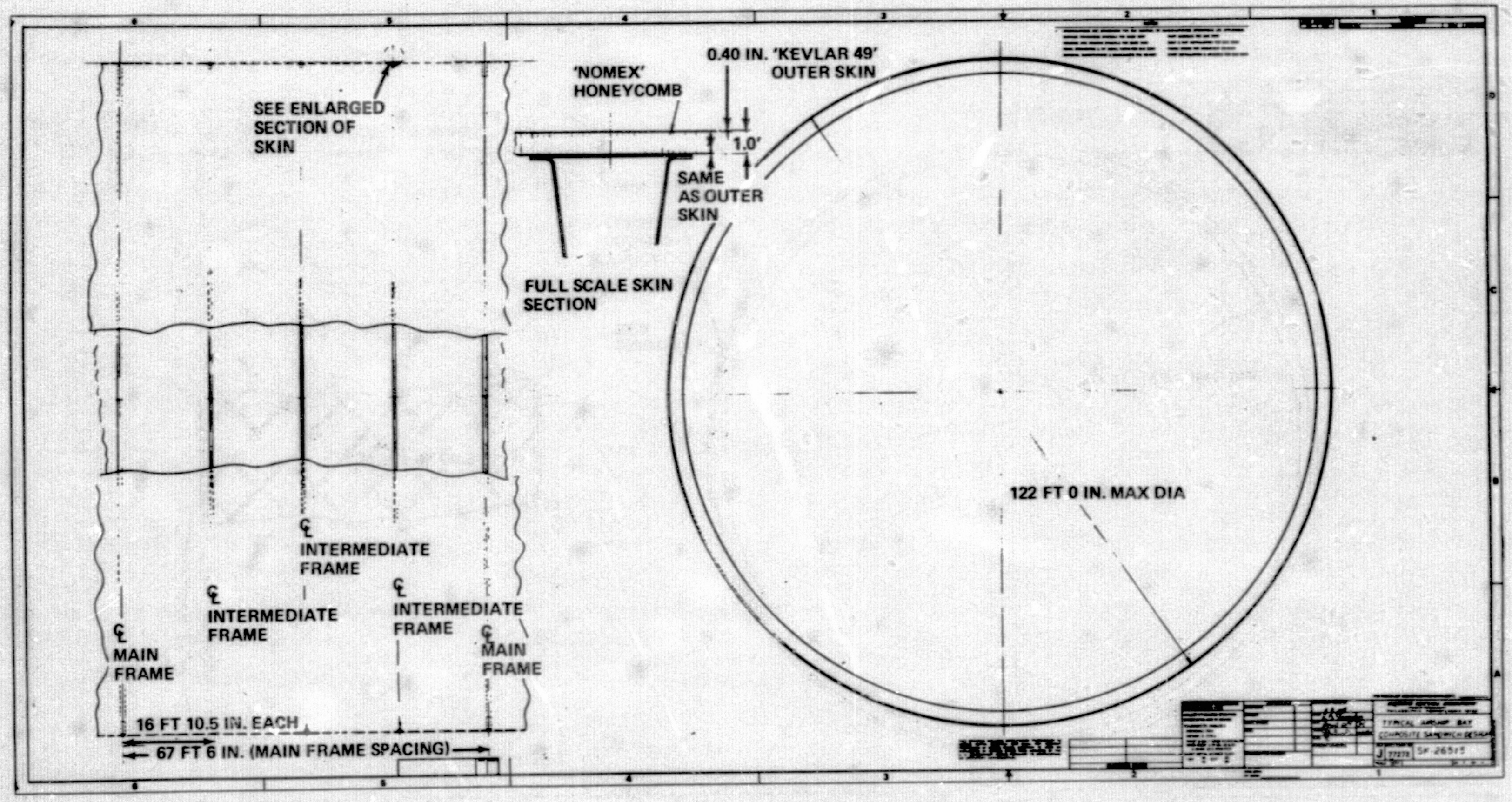


Figure 5–36. Composite Sandwich (Candidate Nc. 5)

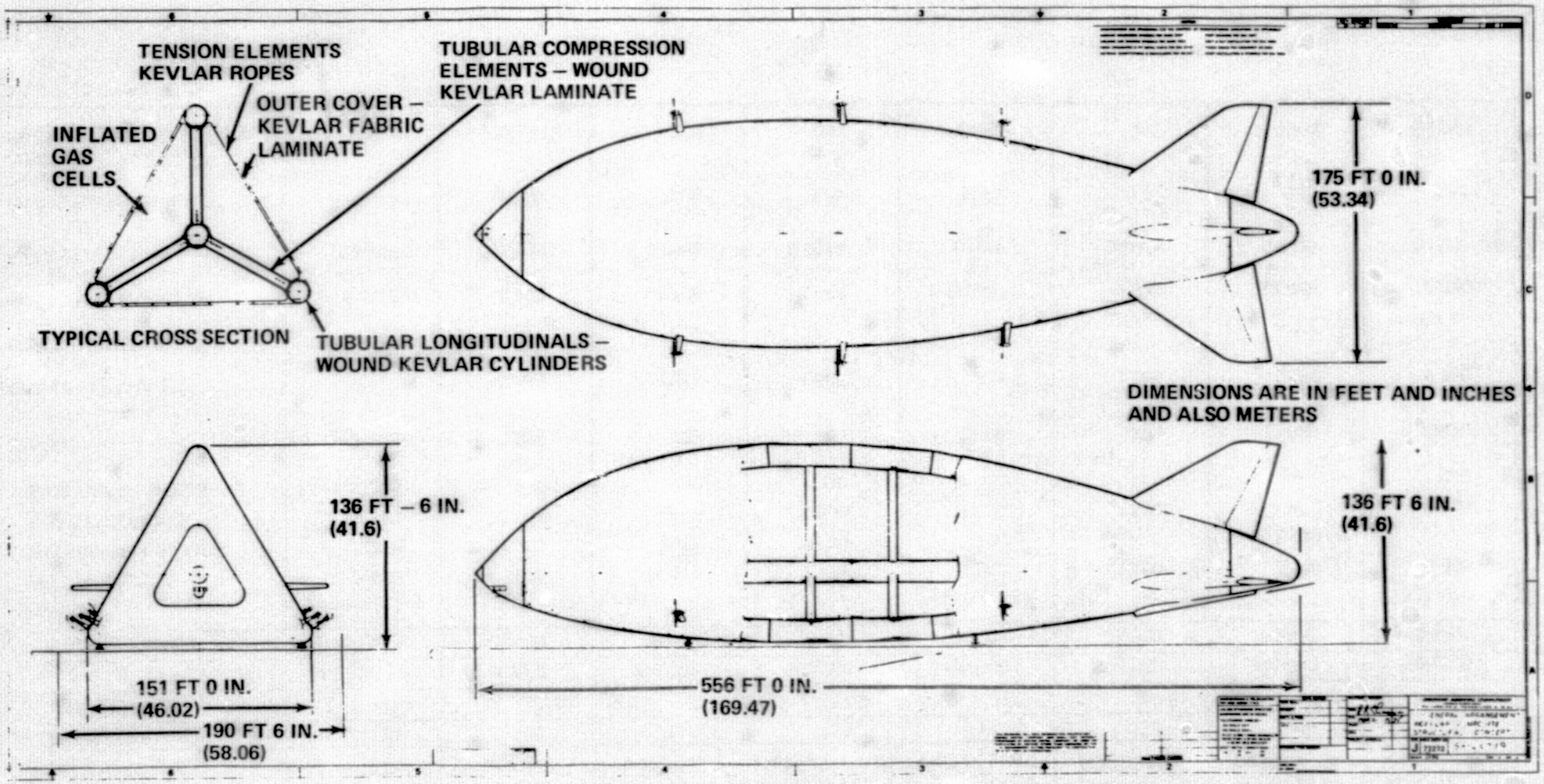


Figure 5–37. Modular Composite (Candidate No. 6)

Table 5–VI. Comparison of Rigid Airship Materials/Structures Concepts

TYPICAL MAIN BAY	1930 STATE-OF-THE-ART		1975 STATE-OF-THE-ART					
	ZRS-4 AKRON	BASELINE CONCEPT	1 ADVANCED ALUM ALLOY	2 COMPOSITES SUBSTITUTION	3 PRESS-RIGID METALCLAD	4 COMPOSITE GEODETIC	5 COMPOSITE SANDWICH	6 MODULAR COMPOSITE
DIAMETER – FT	133	122	122	122	122	122	122	N.A.
BAY LENGTH – FT	73	67.5	67.5	67.5	67.5	67.5	67.5	67.5
VOLUME – FT^3	1,012,500	790,000	790,000	790,000	790,000	790,000	790,000	790,000
SURFACE AREA – FT^2	30,500	26,000	26,000	26,000	26,000	26,000	26,000	30,300
FRAMING								
MAIN FRAME(S)	2,520	2,025	1,610	1,455	1,340	2,150	2,150	3,500
INTERMED. FRAMES	1,380	1,207	955	890	720	–	1,150	–
LONGITUDINALS	2,340	2,030	1,625	1,500	1,030	2,500	–	9,000
SIDE PANEL WIRES	1,020	920	230	230	–	–	–	250
COVER	1,275	1,075	785	785	7,650	785	13,000	930
GAS CELL/VALVES	2,420	2,145	1,585	1,585	200	1,585	1,585	2,700
MISCELLANEOUS	–	–	–	–	200	–	–	–
TOTAL WEIGHT – LBS	10,955	9,402	6,790	6,445	11,140	7,020	17,885	16,380
WEIGHT/VOLUME – LB/FT^3	0.0108	0.0119	0.0086	0.0082	0.014	0.0088	0.0227	0.0207
WEIGHT/AREA – LB/FT^2	0.36	0.36	0.26	0.25	0.43	0.27	0.69	0.54
WEIGHT (PERCENT OF RATIO BASELINE)	–	BASELINE	72%	69%	119%	74%	190%	175%

CONVERSION FACTORS:

ft x 3.28 = m lb x 0.454 = kg

ft^2 x 0.093 = m^2 lb/ft^2 x 4.88 = kg/m^2

ft^3 x 0.028 = m^3 lb/ft^3 x 16.21 = kg/m^3

5.2.4 Drag Reduction

Studies have been conducted to determine means of reducing the high parasite drag of airships. Many different methods have been proposed and some of them tested.[11,70,71] But in spite of much intensive work, the actual achievement of substantial drag reduction for general application seems to be elusive.

The most obvious way of achieving drag reduction is reported in Reference 70 where a 22.4 percent reduction in total airship drag was achieved after numerous protuberances, antennae and fixtures on the ZS2G-1 airship were either removed or faired. This illustrates the importance of a clean design.

Other, more sophisticated means of achieving drag reduction have been proposed. These include compliant skins and boundary layer control. Available test data on compliant skins is inconclusive.[71] If such a scheme could be made to work, it would be attractive because it requires no real sacrifice of volume and no additional machinery. However, handling difficulties would be a real problem with the soft surface involved with this technique.

Analytical studies have been conducted to determine the benefit of boundary layer control in reducing airship drag. These studies have been conducted for a conventional rigid airship with a volume of $3 \times 10^6 ft^3$, ($85 \times 10^3 m^3$), with design speeds of 50, 100, and 200 kts (25.7, 51.4, and 102.9 m/s). Two means of boundary layer control were studied, blowing and suction. A review of available pressure distribution test data[70] indicated that conventional airship hulls do not have large areas of separation, therefore boundary layer blowing which will eliminate these separated areas would not reduce drag significantly. Preventing turbulent flow by continuous boundary layer suction is one of the oldest drag reduction techniques, and has led to a great amount of aerodynamic investigation in connection with high performance aircraft wings. A large number of small width slots are necessary or else a porous surface. Underneath this outer surface is a flow channel to receive the sucked fluid. A body shape with a relatively flat pressure distribution, like an airship hull, is desirable in order to simplify the suction problem by keeping the pressure drop equal across each slot or at each point on a porous surface.

The effect of suction is to stabilize the boundary layer and prevent transition from laminar to turbulent flow. Assuming continuous uniform suction, the skin friction coefficient as a function of Reynolds number is as shown in Figure 5-38, labeled optimum suction. Optimum suction denotes the smallest volume coefficient C_Q (where C_Q = quantity of sucked fluid/free stream velocity times surface area) which just suffices to maintain laminar flow.

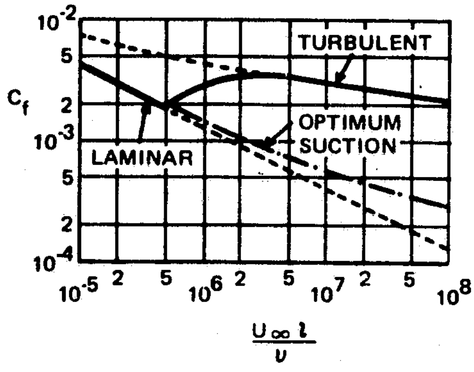


Figure 5–38. Coefficient of Skin Friction of a Flat Plate at Zero Incidence

The relative saving in drag calculated with respect to turbulent drag increases somewhat as Reynolds number is increased. Figure 5-39 shows that it varies from 65 to 85 percent in the range of Reynolds numbers from 10^6 to 10^8.

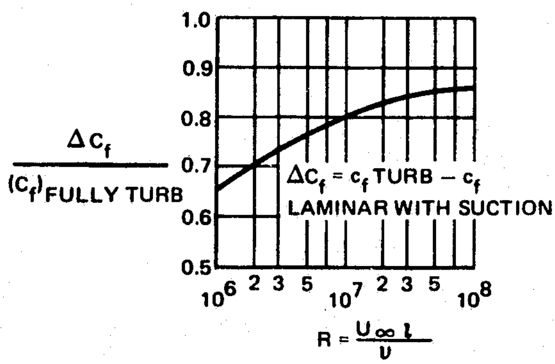


Figure 5–39. Relative Saving in Drag on Flat Plate at Zero Incidence with Suction Maintaining Laminar Flow at Optimum Suction

Table 5-VII shows the possible drag reduction and power requirements, including internal duct losses. As can be noted from the table, the installed power for the BLC configured airship is higher than a conventional airship up to 200 kt (102.9 m/s). In addition, the weight increment for the BLC, including ducts, pumps, additional engines, porous skins and control systems is estimated to be 99,000 lb (44,906 kg). It should further be noted that a practical design to control and maintain the flow under service conditions may be difficult and costly to achieve.

Another method of drag reduction by using discrete slot suction as reported by Pake and Pipitone[11] involves special shaping to achieve favorable pressure gradients over most of the hull. The resulting hull shape is similar to a Griffith type airfoil section. This type maintains favorable pressure gradients over the whole airfoil except for a sudden large pressure increment near the trailing edge. If the boundary layer were removed by suction upstream of this point,

Table 5–VII. Effect of Boundary Layer Control by Suction on Airship Power and Weight

NOTES

- HULL VOLUME = 3×10^6 FT^3
- LENGTH = 487 FT
- DIAMETER = 108 FT
- SEA LEVEL/ISA

DESIGN SPEED ~ KT	50	100	200
VERT. TAIL DRAG AREA, FT^2	31.52	29.84	29.61
HORIZ. TAIL DRAG AREA, FT^2	31.52	29.84	29.61
CONTROL CABIN, FT^2	25.00	25.00	25.00
HULL W/O BLC, FT^2	310.89	284.04	260.44
HULL WITH BLC, FT^2	46.63	42.61	39.07
TOTAL DRAG AREA W/O BLC, FT^2	398.93	368.72	344.66
TOTAL DRAG AREA WITH BLC, FT^2	134.67	127.29	123.29
INSTALLED POWER W/O BLC, HP	1,060	5,318	33,686
PROPULSIVE POWER WITH BLC, HP	358	1,836	12,050
POWER REQUIRED FOR BLC, HP	6,600	6,600	6,600
INSTALLED POWER WITH BLC, HP	6,958	8,436	18,650
POWER INCREMENT FOR BLC, HP	+5,898	+3,118	-15,036
WEIGHT INCREMENT FOR BLC, LB	+99,000	+99,000	+99,000

CONVERSION FACTORS:

1 FT = 0.3048 M
1 FT^2 = 0.0929 M^2
1 FT^3 = 0.0283 M^3
1 LB = 0.454 KG
1 KT = 0.514 M/S

separation would be prevented. The experimental data of Reference 11 indicates this system is capable of reducing the propulsive power required by 15 to 25%. However, mechanical design work needs to be performed for this system to determine the effects on weight empty.

It can be concluded from this study that additional work needs to be done before a BLC system is practical. It appears that the best approach to drag reduction at this time is to adhere to good design practice and design an aerodynamically smooth airship.

5.2.5 Thrustor Concept Trade-Off

5.2.5.1 Summary and Conclusions

The typical lighter-than-air craft has unique characteristics that must be considered in the selection of the most suitable thrustor concept. These are its high parasite drag, high inertia, low speed, and low to moderate altitude flight envelope. All of these factors point to a requirement for high efficiency at hover and low speed and a rapid response capability. In addition, reverse (or negative) thrust capability may be desired on some hybrid LTA concepts. A propeller (or prop-rotor) is clearly the only thrustor concept that meets the requirements discussed above, although a case might be made for a ducted fan/propeller (very high bypass) at the higher flight speeds or as a compact vectoring system on the hover mode. Figure 5-40 illustrates the thrustor concept selection process and the final selection.

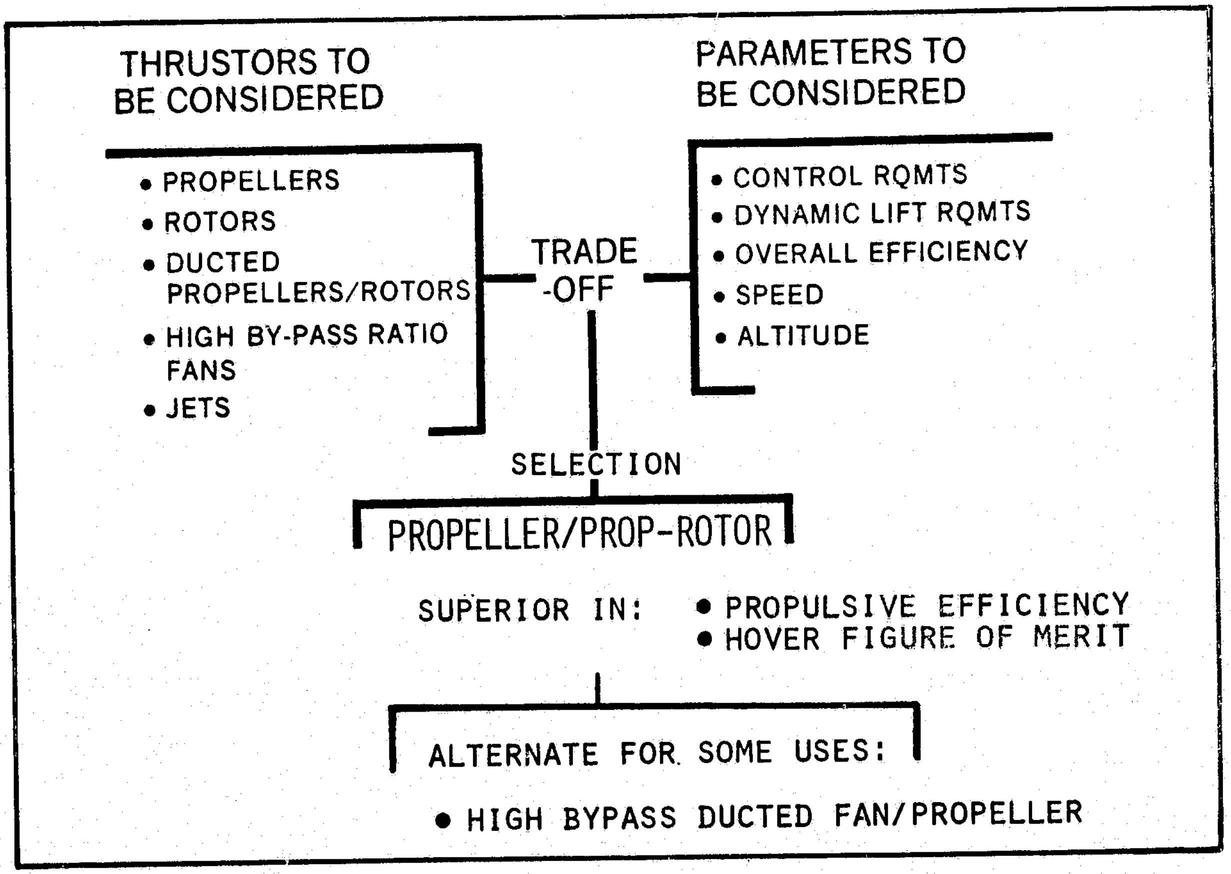


Figure 5–40. Thrustor Concept Selection Process

5.2.5.2 Study Results

Airship inertias in pitch and yaw are large compared to conventional aircraft. This leads to a requirement to generate large thrust forces for control. Since the definition of control requirements was not a part of this study, only a qualitative assessment of its impact on thrustor selection was made. In general, high thrusts and rapid response are desirable attributes in generating control moments. In addition, there may be a requirement to generate reverse thrust to augment maneuverability, especially in the terminal area. The propeller or prop rotor is ideally matched to these specifications. High bypass ratio fans and jet concepts generally do not have the required flexibility. This flexibility may be obtained by the addition of thrust vectoring or variable pitch fans but at the cost of additional weight and drag.

The high parasite drag of LTA vehicles, coupled with the low speed, moderate altitude flight envelope and the requirement for long range will only be offset by the highest possible propulsive efficiency. The forward flight propulsive efficiency of various thrustor candidates are compared in Table 5-VIII for speeds of 100 and 200 kts (51.4 and 102.9 m/s).

Table 5–VIII. Comparative Evaluation of Airship Engine Cycles

Concept	Propulsive Efficiency η_P	
	100KT (51.4 M/S)	200KT (102.9 M/S)
Optimum Propeller	.82	.88
Turboprop AF=180	.54	.79
Turbofan (Bypass = 10)	.43	.69
Turbofan (Bypass = 6)	.30	.56
Turbojet (Bypass = 0)	.165	.32

Table 5-VIII clearly shows that the propeller (or prop rotor) is the most efficient thrustor for the relatively low speed regime of the airship. A case might be made for a ducted fan/propeller (very high bypass) at higher speed levels (combined with some form of drag reduction). In addition, where static thrust capability is required, the prop/rotor of moderate disc loading has the highest figure of merit when compared with high disc loading devices.

5.3 Preliminary Design

Survey of the potential advanced airship concepts led to a selection of six study configurations (Figure 5-17):

- Conventional Non-Rigid
- Conventional Rigid
- Deltoid (Dynairship)
- Guppoid[39] (Megalifter)
- Helipsoid
- Heli-Stat

The principal tool used to generate data for this study is the "CASCOMP" airship sizing computer program (described in Appendix C). The study configurations were analyzed through the use of this program in developing weight, performance, and sizing trends for each configuration by varying the following parameters in the range of 3000 lb (1365 kg) to 6,000,000 lb (2,720,000 kg) gross lift capability.

Buoyancy Ratio	Cruise Speed	Range
100%	200 kt (102.9 m/s)	5,000 NM (9,260 km)
75%	100 kt (51.4 m/s)	2,000 NM (3,704 km)
35%	50 kt (25.7 m/s)	300 NM (556 km)

5.3.1 Configuration Design/Integration

Preliminary definition of the candidate study configurations was established during the survey/selection task by preparation of the sizing study 3-view general arrangement drawings presented in paragraph 5.1.1. Geometry analysis of these configurations is presented in Figures 5-41 through 5-44. The geometry of the Heli-Stat is not presented separately as the hull was considered to be the same as the conventional sized airship from a geometry point of view.

Configuration development of the selected airship designs continued through the parametric design phase to establish the parametric design, performance, and weight factors consistent with the application of modern technology. The resulting representative configurations are discussed in the following. Additional design discussion of the soft goods components of these configurations is presented in Appendix B.

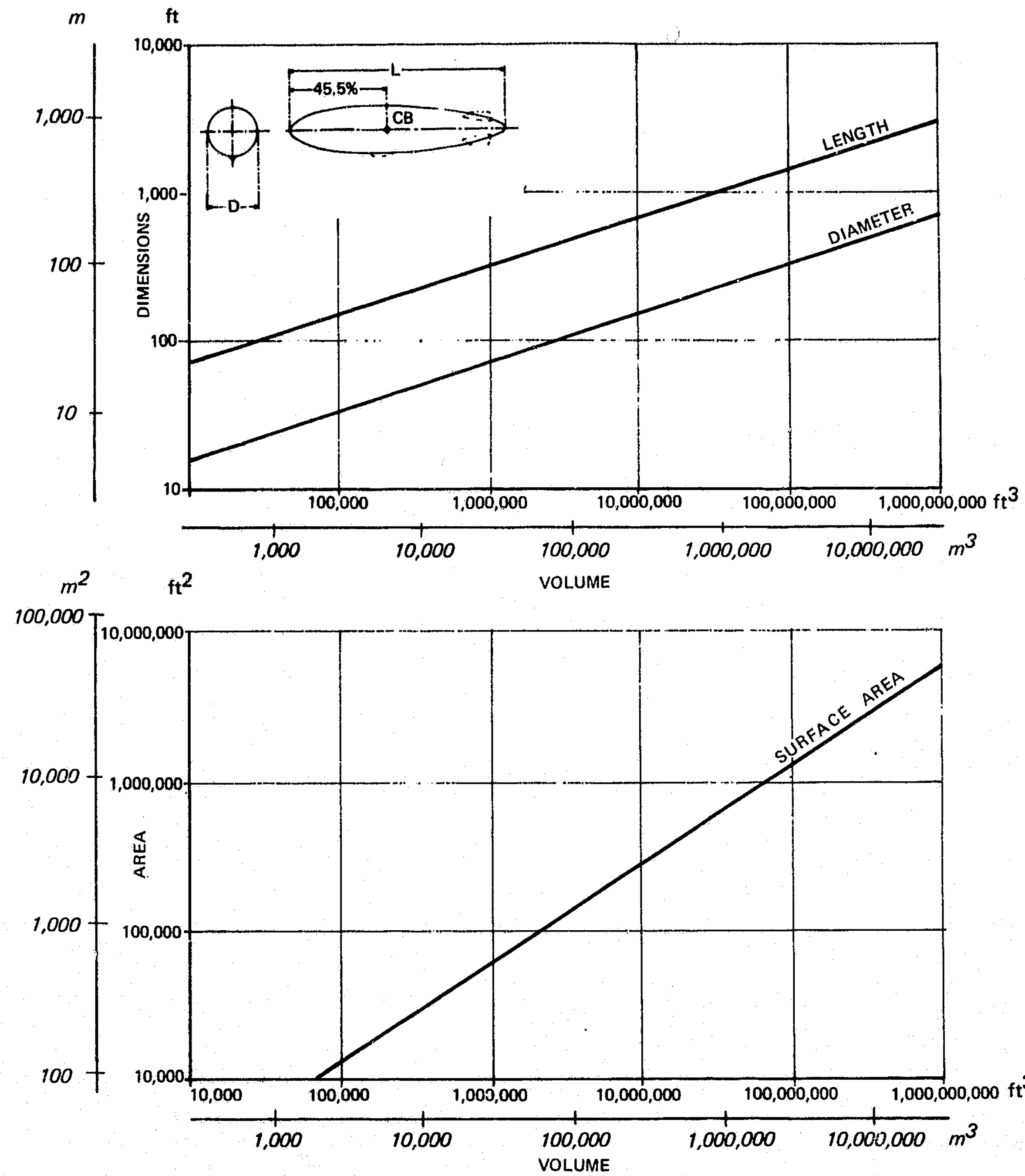


Figure 5–41. Geometry Study — Conventional Airship (Rigid and Non-Rigid)

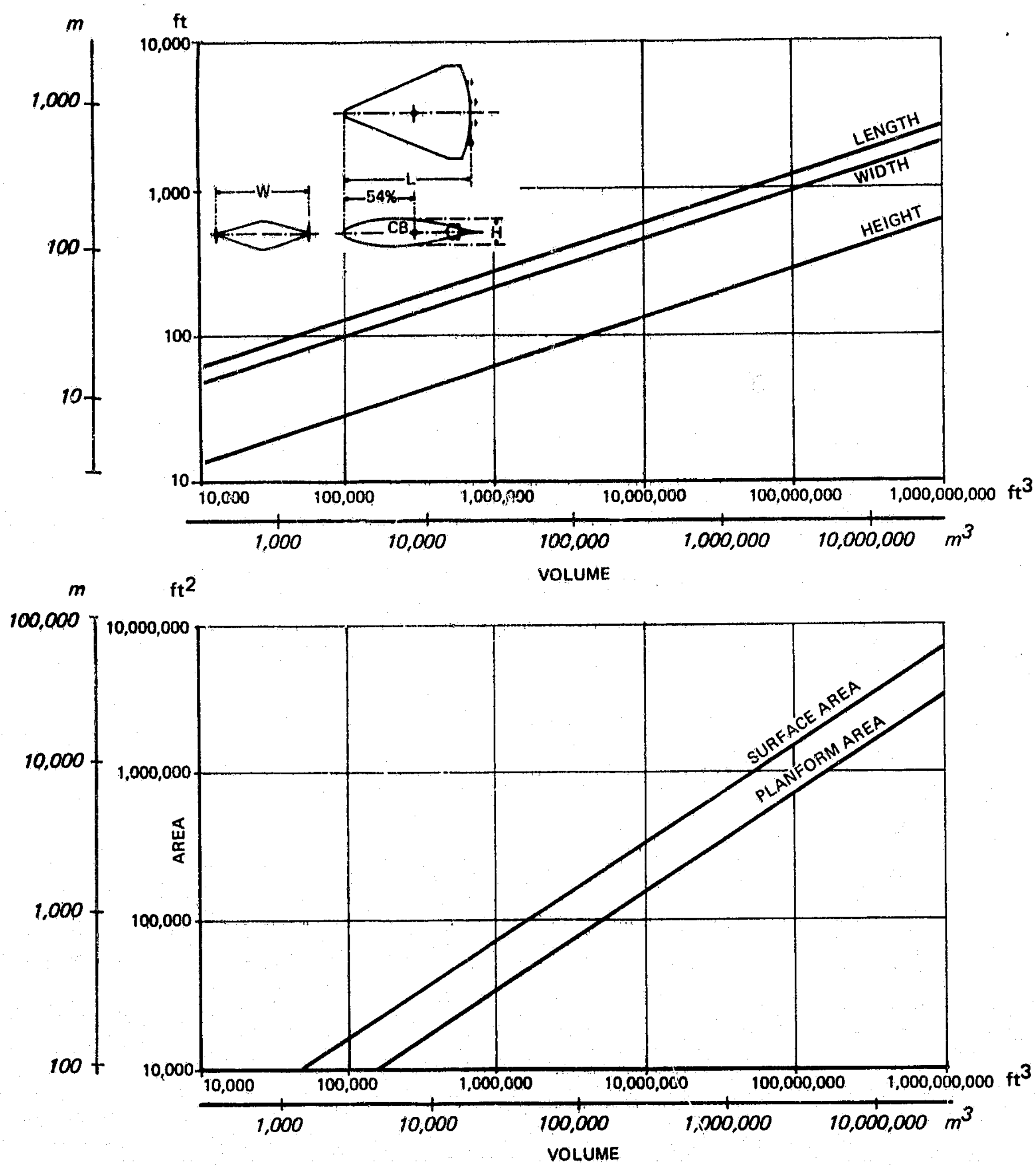


Figure 5–42. Geometry Study – Deltoid (Dynairship)

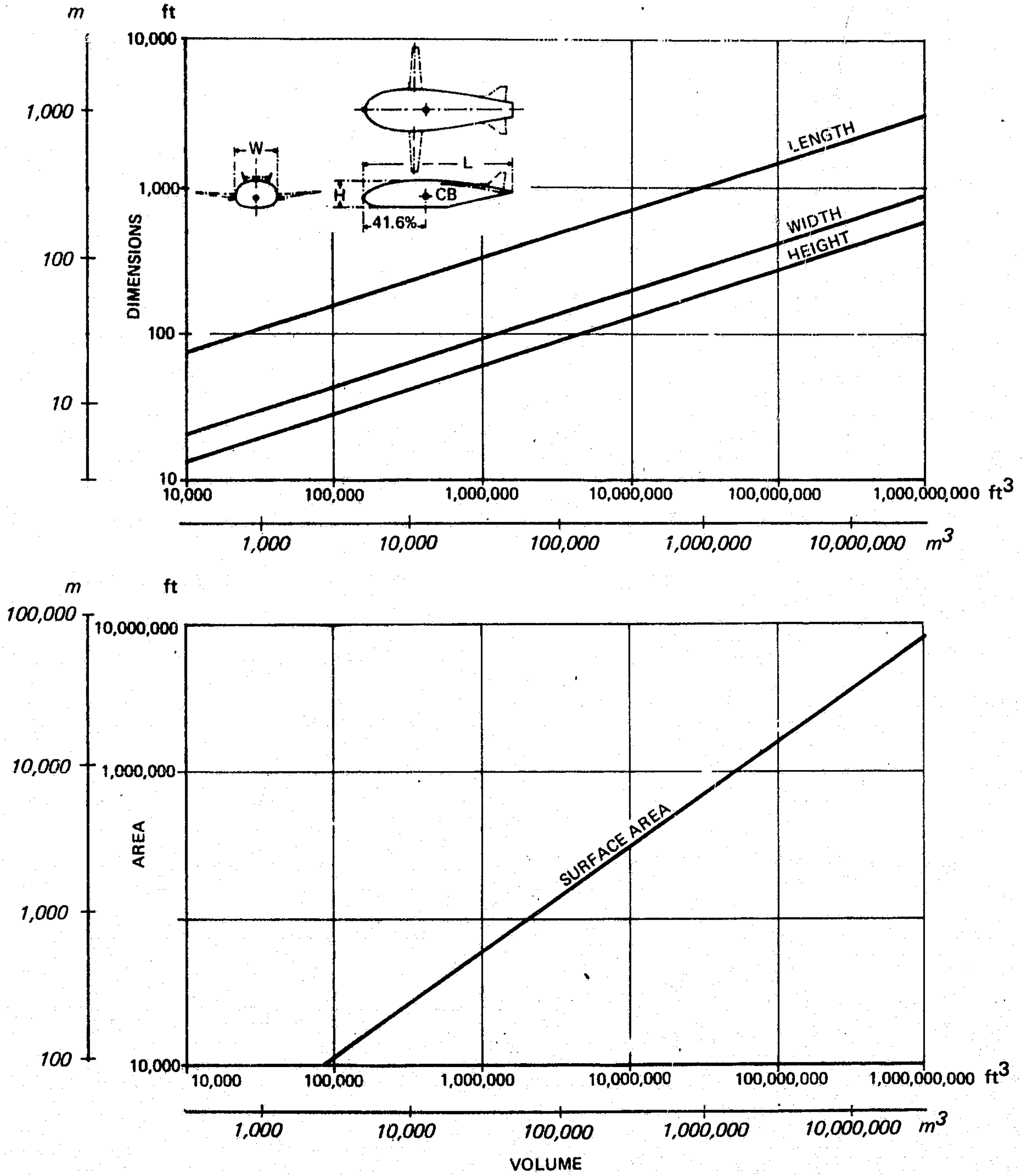


Figure 5–43. Geometry Study – Guppoid (Megalifter)

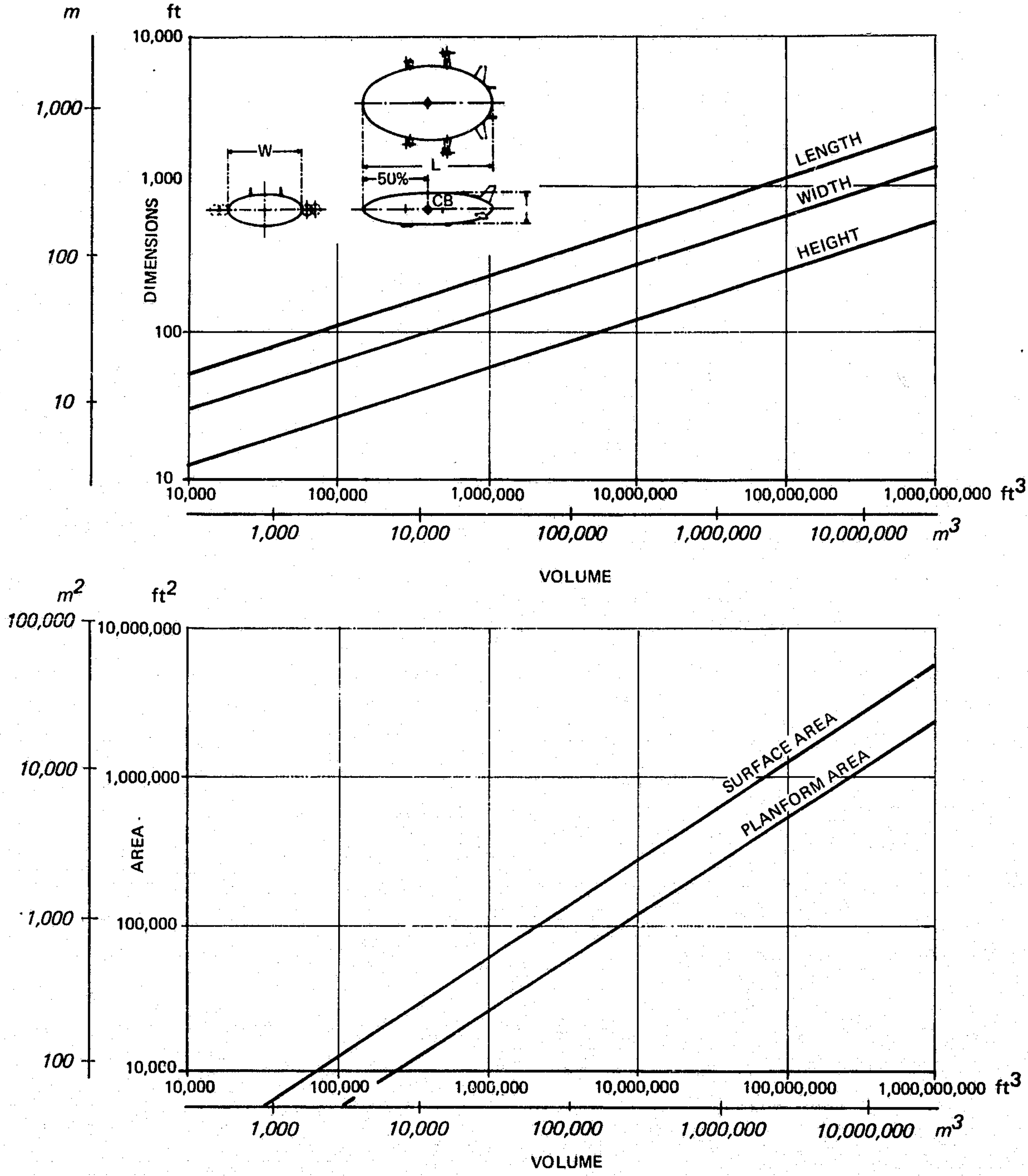


Figure 5–44. Geometry Study – Helipsoid

5.3.1.1 Conventional Non-Rigid Airship

The non-rigid airship appears to gain appreciably from the application of modern technology. This is due to the development of the aramid fibre technology, especially the KEVLARs in a triaxial weave fabric. Whereas, previous envelopes of neoprene coated cottons or dacron were extremely heavy (like 24-29 percent of gross lift), use of the advanced fabrics (and films) reduces this weight fraction by a factor of nearly three.

Speed limitations on the modern non-rigid airship due to the high internal pressurization required, appear to be of the order of 100 kt (51.4 m/s). Also, based on the maximum fabric strength seaming capability of 1000 lb/in.(175.13N/mm), the non-rigid size range should be limited to a diameter of about 160-180 ft (40-55m) (corresponding to the 100 kt (51.4m/s)limit) resulting in a volume limitation slightly more than 10,000,000 ft^3 (286,000 m^3). Even this capability is not now available and considerable development is required to match seaming strengths to the material strength characteristics. The representative non-rigid configuration, as exemplified by the 10,000,000 ft^3 (286,000 m^3) airship of Figure 5-45, has a fineness ratio of 4.5 with four rudderators arranged symmetrically on the stern at a 45° angle to the vertical plane as an example. The crew and payload accommodations are in a faired external car suspended from a typical twin catenary system. The turboshaft engines are internally mounted (within the car) driving variable pitch prop-rotors. Although not shown, other engine-propeller arrangements can be made to provide (through tilting prop-rotors) additional lift for overload take-offs as well as a capability for providing low-speed controllability.

The configuration includes provisions for the typical ballonet and air pressurization system to allow altitude capability and longitudinal trim adjustment. A ballonet capacity of 25 percent of maximum gas capacity is shown.

5.3.1.2 Conventional Rigid Airship

Figure 5-46 illustrates the representative conventional rigid airship analyzed in this program. Although not necessarily the optimum fineness ratio for a rigid airship, the L/D of 4.5 was chosen for convenience. Only detailed structural design and weight/performance analyses can optimize this ratio for the modern airship.

The structural arrangement is the selected composite geodetic concept from 5.2.3. Turboshaft engines are installed within the hull and drive tilting prop-rotors to provide low speed control as well as propulsion. Flight control systems will be based on fly by wire concepts developed for helicopters and advanced airplanes.

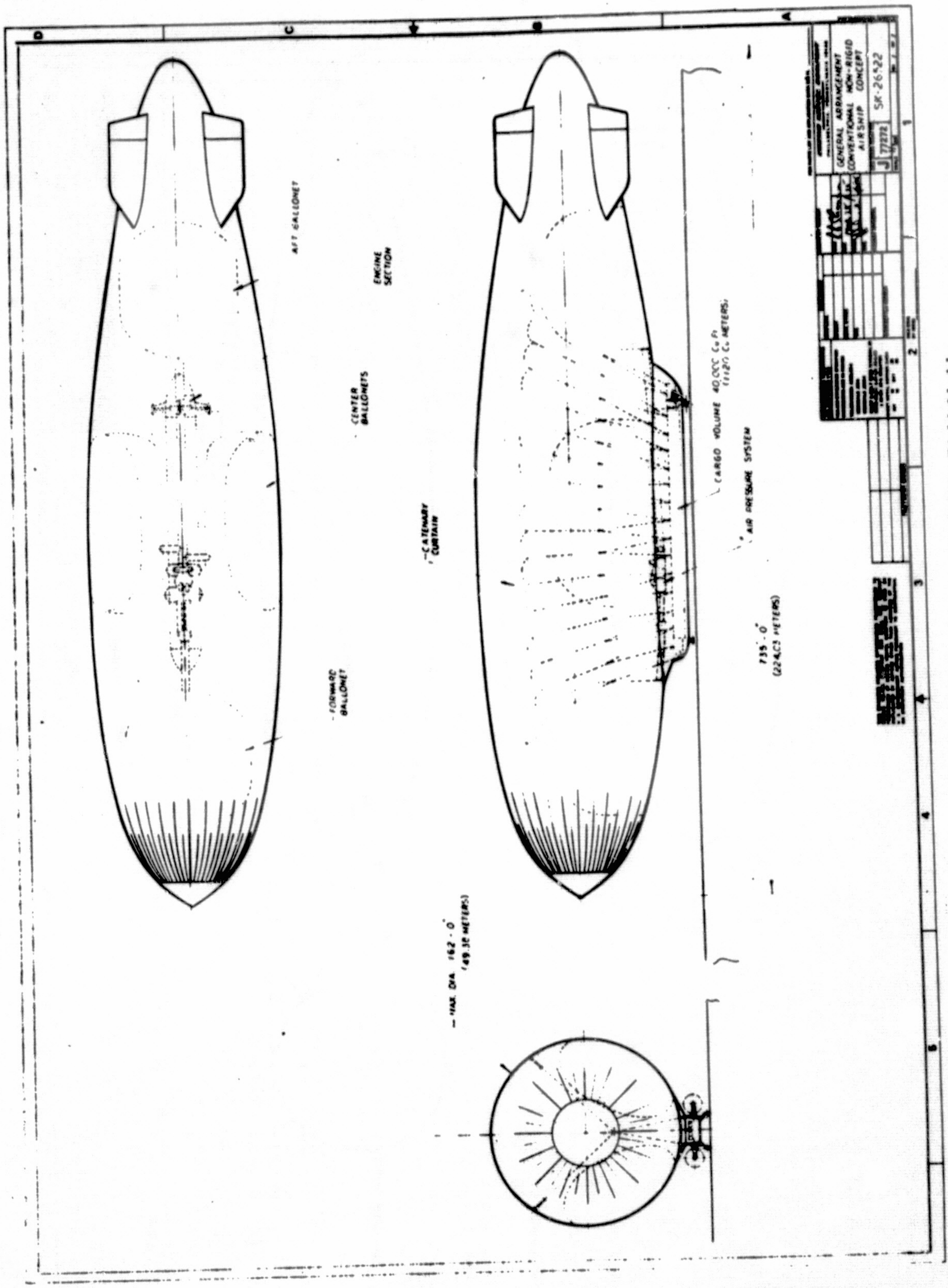


Figure 5–45. General Arrangement – Conventional Non-Rigid Airship

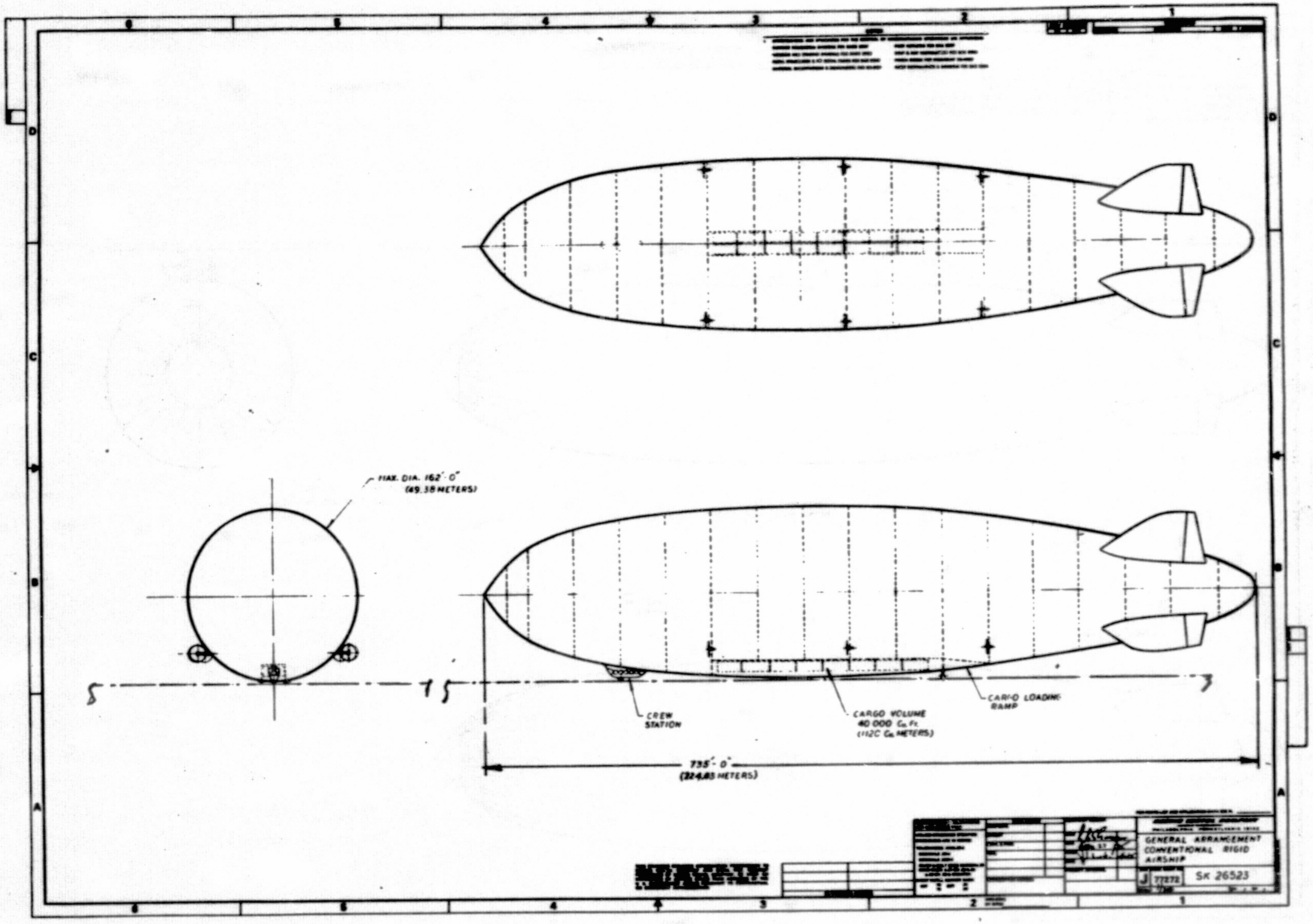


Figure 5–46. General Arrangement – Conventional Rigid Airship

Since the airship depicted is fully (or nearly) buoyant, ballast (or weight replacement) systems are required for both fuel-burnoff and payload transfer. Since the turboprop engine exhaust has a high temperature and large air quantity/power ratio, water recovery from the exhaust (even though theoretically possible) is probably not practical on a weight efficiency basis. Further design efforts are required to solve this problem.

In addition, ballast replacement when transferring payload will be a serious problem if the airship is not to be constrained to operations from fixed bases where heavy tie down and handling equipment (or other advanced ground handling systems) are available. Development of freight-hauling systems) are available. Development of freight-hauling missions into just-developing remote areas may require a system similar to that recommended in Reference 11 by E. Mowforth, that of equal ballast lift-on as payload is dropped off.

5.3.1.3 Deltoid (Dynairship) Concept

The partially buoyant Deltoid concept shown in Figure 5-47 has a low aspect ratio highly swept delta shape with a thickness ratio of about 22 percent. The structure depicted is based on Aereon Dynairship patents (see Appendix A). However, time and budget did not permit a weight analysis; therefore the parametric weight trends are based on a typical composite geodetic rigid structure as discussed in paragraph 5.2.3.

A STOL propulsion system arrangement using turboshaft/propeller combinations mounted along the trailing edge of the body provides propulsion but no control potential (other than some small directional control possibility through differential propeller control).

A Deltoid with the optimum buoyancy ratio probably will not require a ballast recovery system for fuel burn-off in most missions. For this concept, the aerodynamic lift may be reduced progressively to trim and maintain altitude. However, if the buoyant lift is more than the O.W.E., a load/unload sequencing system, a ballast/load transfer system, or heavy ground support equipment (like "mules") will be required for terminal loading/unloading operations and parking/hangaring equipment will be necessary.

5.3.1.4 Guppoid (Megalifter) Concept

The partially buoyant Guppoid airship illustrated in Figure 5-48 is based on the concepts of the Megalifter Company (Appendix A). The hull may be shaped as shown here or may be that of a conventional rigid type. However, structural integration of the large lightly loaded light-weight space frame of the airship with a highly loaded wing providing approximately 50 percent of the lift is a major task. Although

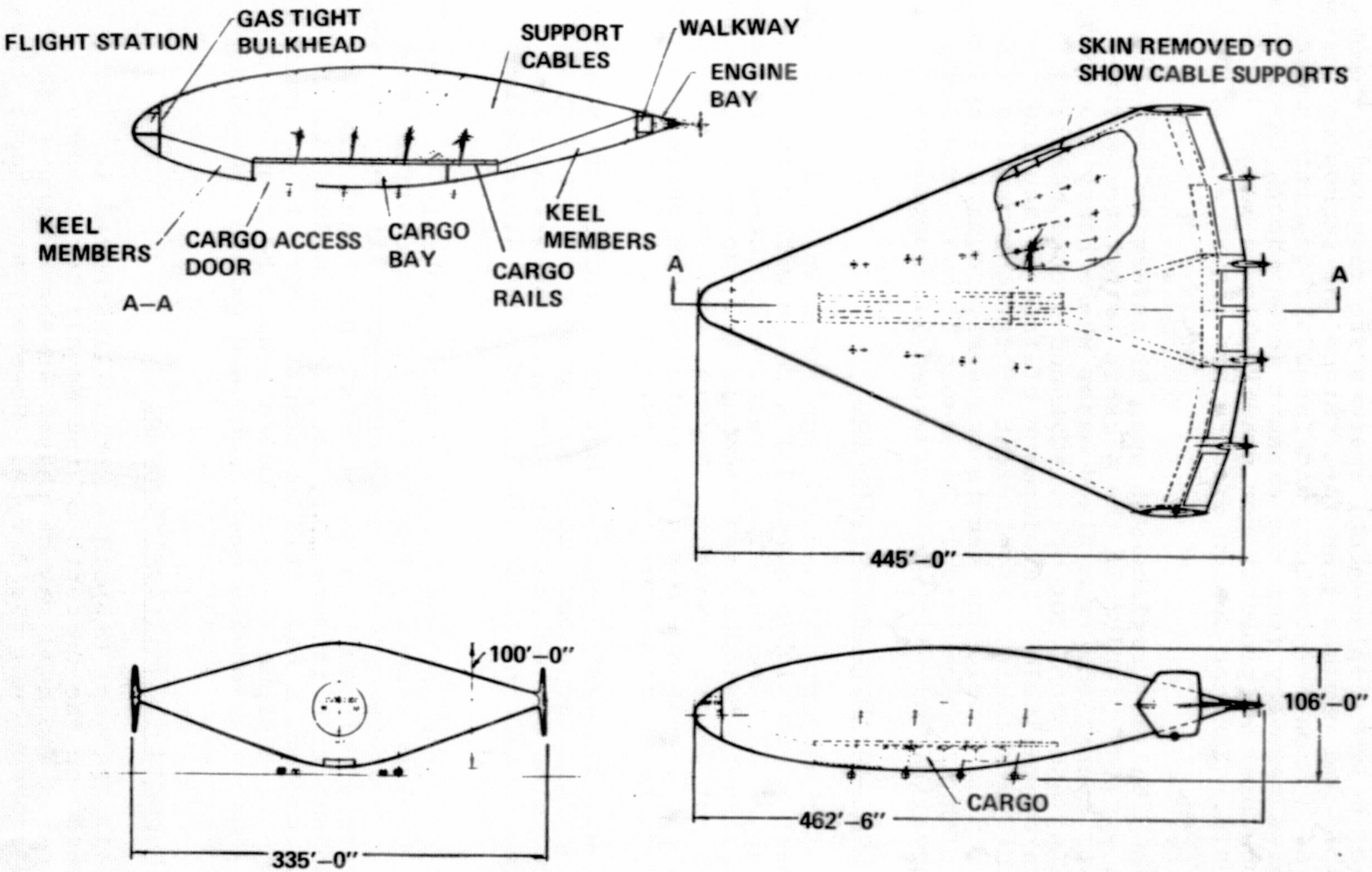


Figure 5–47. General Arrangement – Deltoid (Dynairship)

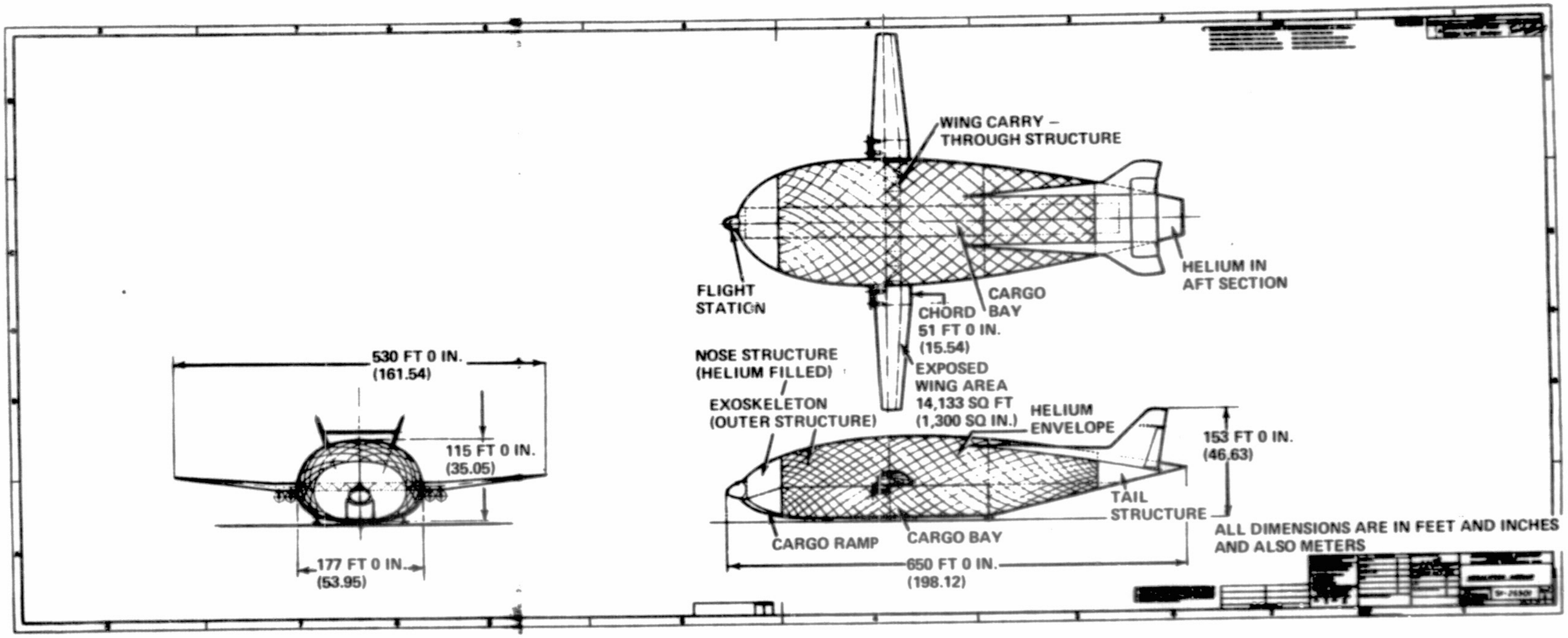


Figure 5–48. General Arrangement – Guppoid (Megalifter)

superficially resembling an airplane, the fuselage structure must be extremely efficient in the structure weight/wetted area ratio--about 10 to 15 times better than that of the typical airplane.

The pure STOL approach is shown here with turboshaft engines and propellers deployed along the wing. Other layouts are possible if low speed control capability is desired. The same comments made above (paragraph 5.3.1.3) with regard to ballast are applicable to the Guppoid concept.

5.3.1.5 Helipsoid Concept

The partially buoyant Helipsoid V/STOL airship illustrated in Figure 5-49 is an attempt to achieve the best compromise shape for a moderately high speed airship considering optimum structural, aerodynamic, and control requirements along with a compact lifting body.

The selected composite geodetic rigid structures approach will include load spreader panels and KEVLAR rope catenaries to achieve the optimum shape. The turboshaft engines and tilting prop-rotors are disposed about the center of buoyancy to provide, through collective and differential collective control systems, both lift and control as well as propulsion. Comments made above (paragraph 5.3.1.3) with regard to ballast generally apply to the Helipsoid. However, in a VTOL variant, negative thrust on the prop-rotors during landing operations may be used to eliminate ballast requirements. Restraint after power shutdown might, of course, be required.

5.3.1.6 Heli-Stat Concept

The partially buoyant Heli-Stat V/STOL airship illustrated in Figure 5-50 is an attempt to marry a conventional rigid airship with existing helicopter dynamic systems to provide an easily developed (low RDT&E Costs) heavy lift transport capability in an early time-frame. Integration of the helicopter rotor (and tail rotor) thrust through collective and differential collective control systems (as well as main rotor cyclic control) can provide the lift and control as well as the propulsion capability. At low speeds the rotors can provide efficient propulsion but at higher speeds (like 150 kt(77.2 m/s) or higher) the rotor propulsive efficiency will be inferior to that available from the axially-mounted prop-rotor. However, this compromise may be sufferable in the interest of expediency.

Integration of the heavily loaded dynamic systems (and their supports) with the lightly loaded light weight space framework of the airship is again a formidable problem. For purposes of this design study, the composite geodetic rigid airship structure was assumed. Buoyancy and ballast comments made above (paragraph 5.3.1.5) for the Helipsoid concept are generally applicable.

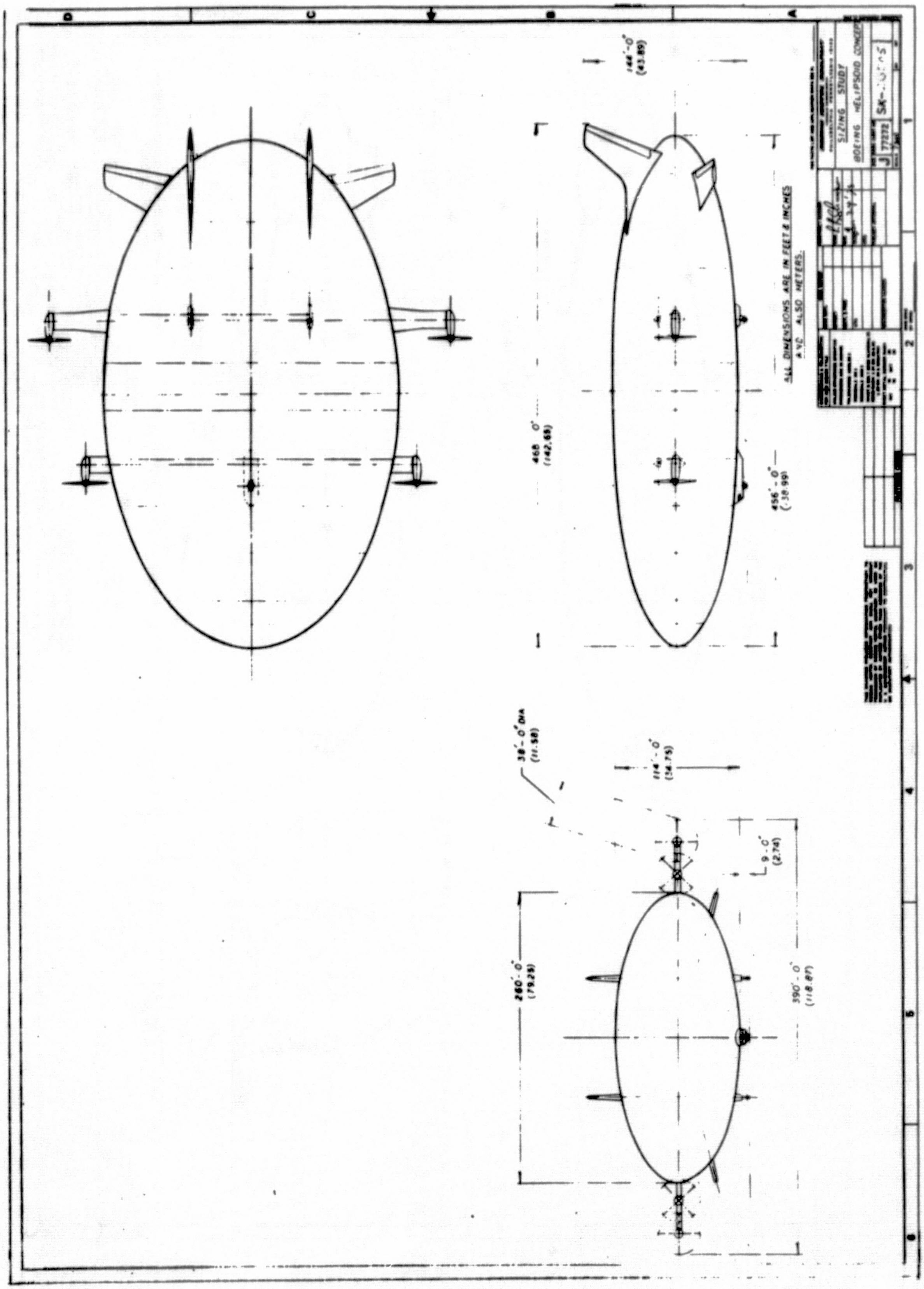


Figure 5–49. General Arrangement – Helipsoid

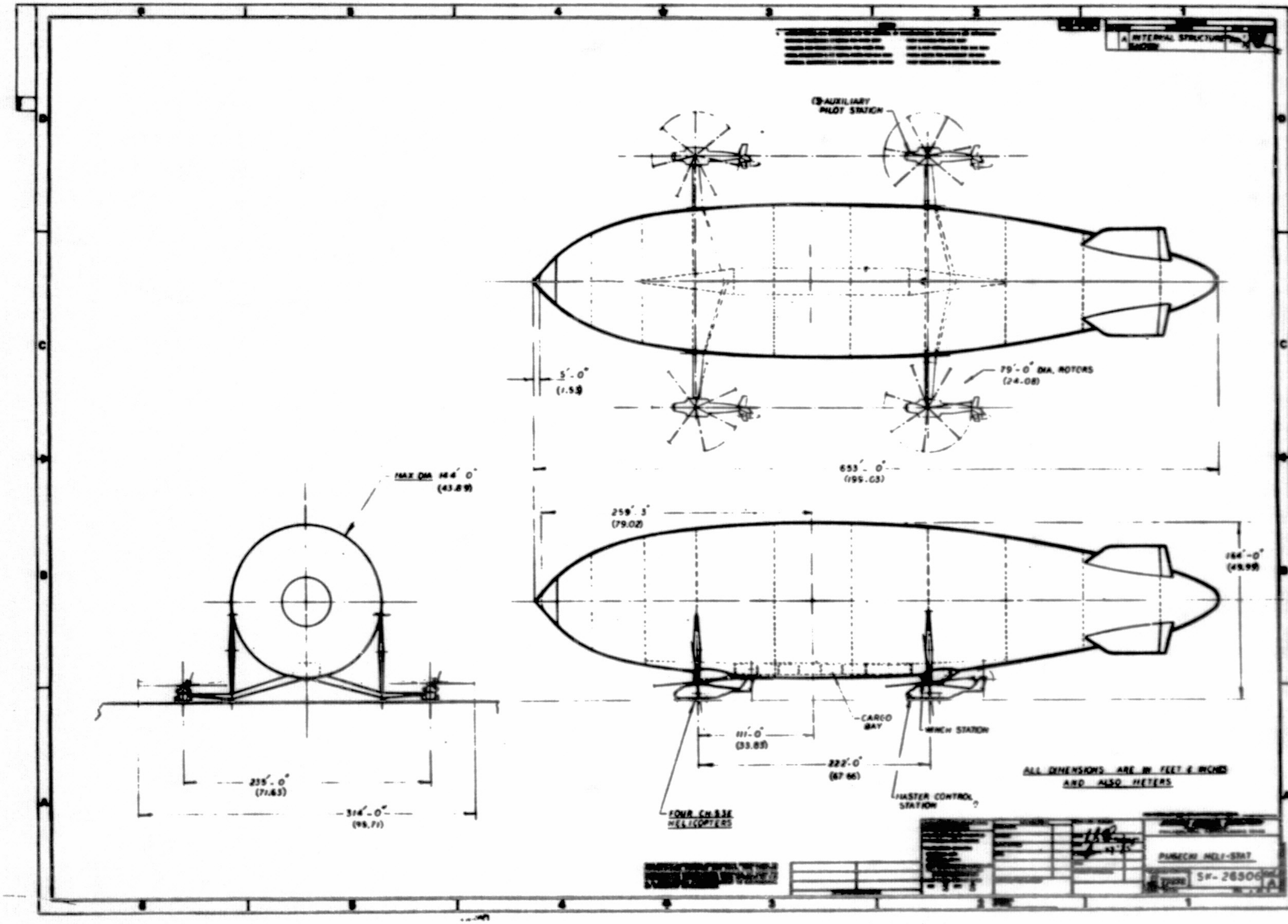


Figure 5–50. General Arrangement – Heli-Stat

5.3.2 Configuration Optimization

While the vehicle parametric design activities under this contract did not permit analysis of other modern airship system requirements, revival of any modern airship concept will require significant effort in these areas to provide a fully optimized configuration:

5.3.2.1 Stability and Control Systems

Requirements for stability and control in all flight modes, especially the low speed and hover modes must be addressed in depth.

5.3.2.2 Landing Gear Systems

Geometry of these immense space systems require light weight approaches to landing gears--or weight bogies will be easily exceeded.

5.3.2.3 Crew Systems

Much work is needed to define a minimum crew complement and efficient crew systems through task analyses similar to Reference 63. The low speed/productivity of the airship requires high utilization and long flight times thereby further emphasizing a minimum flight crew complement as well as reasonable on and off-duty pay schedules.

5.3.2.4 Payload Handling Systems

Whether these are high capacity hoisting/slinging systems or high capacity floor/roller systems, etc., light-weight concepts will require considerable development to achieve efficient low-cost systems.

5.3.2.5 Ballast Management Systems

Where required, the use of ballast, ballast replacement, and ballast handling/management systems will require extensive development for future airships.

5.3.2.6 Ground Handling/Hangaring Systems

A major undertaking, development of these systems to reduce the manpower requirements to an absolute minimum (perhaps near-zero) is a significant future task.

5.4 Parametric Analysis

This section of the document describes the parametric analysis that was conducted to evaluate the relative merits of the lighter-than-air concepts identified in Section 5.1. The six concepts selected for parametric analysis (Figure 5.17) cover the range of buoyant and partially buoyant air vehicles, all with the potential for VTOL if proper attention is given to propulsion and control systems. All of the vehicles examined during this parametric study were sized to a forward speed requirement. VTOL capability was not explicitly addressed in this study since it would not affect the relative ranking of the concepts.

The rationale for concept selection and a brief description of each has been discussed previously in Sections 5.1 and 5.3. In the following paragraphs, the significant parametric analysis ground rules, methodology, and the parametric results will be discussed. Because of the large number of concepts studied, no attempts were made at vehicle optimization.

5.4.1 Parametric Analysis Ground Rules

Salient parametric analysis ground rules are discussed in this section. These include the range of variables studied, the design missions, and the study ground rules affecting design and performance.

5.4.1.1 Range of Variables Studied

Three missions, three speeds, at least two buoyancy ratios and six LTA concepts were evaluated during this study. Table 5-IX shows the range of parametric variables. For each combination of conditions on the table, gross life varied from approximately 60,000 to 6,000,000 lb (27,216-2,721,600 kg). Mission payload available was determined at each point.

5.4.1.2 Design Mission Requirements

Three design missions are identified and used for the parametric analysis. These are a short range mission (3000 NM (556 km range), a transcontinental mission of 2000 NM (3,704 km) range and an intercontinental mission of 5000 NM (9,260 km) range. Each of six lighter than air concepts selected for study were flown through these missions. The conventional rigid

Table 5–IX. Range of Parametric Variables

MISSION →	SHORT RANGE									TRANSCONTINENTAL									INTERCONTINENTAL								
BUOYANCY RATIO →	1.0			.75			.35			1.0			.75			.35			1.0			7.			.35		
CONCEPT ↓ / SPEED KNOT →	50	100	200	50	100	200	50	100	200	50	100	200	50	100	200	50	100	200	50	100	200	50	100	200	50	100	200
CONVENTIONAL RIGID	X	X	X							X	X	X							X	X	X						
CONVENTIONAL NON-RIGID	X	X	X							X	X	X							X	X	X						
HELIPSOID				X	X	X	X	X	X				X	X	X	X	X	X				X	X	X	X	X	X
MEGALIFTER				X	X	X	X	X	X				X	X	X	X	X	X				X	X	X	X	X	X
HELISTAT				X	X	X	X	X	X				X	X	X	X	X	X				X	X	X	X	X	X
DYNAIRSHIP				X	X	X	X	X	X				X	X	X	X	X	X				X	X	X	X	X	X

CONVERSION FACTOR: 1 KT = 0.514 M/S

and non-rigid airships were flown through these missions with a buoyancy ratio of 1.0. The other four partially buoyant concepts (Helistat, Megalifter, Dynairship and Helipsoids) were evaluated at buoyancy ratios of 0.35 and 0.75. Table 5-X summarizes the three LTA design performance missions.

5.4.1.3 Parametric Analysis Ground Rules

Table 5-XI summarizes the salient ground rules utilized for this study. They are grouped according to major system or technical discipline. Other ground rules used in this study have been discussed in previous sections. More detailed weights ground rules and assumptions are described in detail in Section 5.4.2.6.

5.4.2 Methodology

The methods developed or used in generating the information presented in Section 5.4 are documented in this section. Where standard methods are used, they will be briefly explained and referenced. Unique new methods will be fully explained.

5.4.2.1 Comprehensive Airship Sizing and Performance Computer Program (CASCOMP)

The principal tool used to generate data for this study is the Comprehensive Airship Sizing and Performance Computer Program (CASCOMP). Weight, performance and sizing trends were developed through the use of this program. The program's purpose is to rapidly provide airship sizing and mission performance data. It is used to define design details such as engine size and number, component weight build ups, required propulsive power and physical dimensions of airships which are designed to meet specified mission requirements.

CASCOMP may be used for sizing airships for which the gross lift, type of hull (conventional or lifting body), and the mission profile are specified. Alternately, it may be used for mission calculation for which sizing details and geometry are known.

Table 5–X. Summary of LTA Design Missions

PARAMETER \ MISSION	SHORT RANGE	TRANSCONTINENTAL	INTERCONTINENTAL
RANGE (STILL AIR)	300 NM (556 km)	2,000 NM (3,704 km)	5,000 NM (9,260 km)
CRUISE ALTITUDE	2,000 ft ISA (610 m ISA)	13,000 ft ISA (3,962 m ISA)	2,000 ft ISA (610 m ISA)
CRUISE SPEED*	50, 100, 200 kt (25.7, 51.4, 102.9 m/s)	50, 100, 200 kt (25.7, 51.4, 102.9 m/s)	50, 100, 200 kt 25.7, 51.4, 102.9 m/s
RESERVES	50 NM (93 km) DIVERSION & 10% INITIAL FUEL	250 NM (463 km) DIVERSION & 10% INITIAL FUEL	250 NM (463 km) DIVERSION & 10% INITIAL FUEL
DESIRED PAYLOAD	50–100 TONS	50-100 TONS	100 TONS
DESIGN ALTITUDE (FOR HULLS, PROP/ ROTORS AND ENGINE SIZING)	5,000 ft ISA (1,524 m ISA)	15,000 ft ISA 4,572 m ISA	5,000 ft ISA (1,524 m ISA)

*CRUISE SPEED AT CRUISE ALTITUDE

CONVERSION FACTORS:
1 NM = 1.852 km
1 ft = 0.305 m
1 kt = 0.514 m/s
1 TON = 0.9072 kg

Table 5-XI. Parametric Analysis Ground Rules

- Lift/Propulsion System
  - 4 LTC 4V-1 turboshaft engines (Rubberized), SFC @ S.L. STD. = 0.408
  - 4 Propellers and/or rotors
  - No cross shafting
  - Transmission efficiency = 97%
  - Buoyant Fluid: 97% pure helium (63.96 lb Lift/1000 ft^3) (1,026.96 kg Lift/1000 m^3)
- Weights
  - 25% weight reduction in structural components relative to 1930's technology
  - Landing gear weights vary with buoyancy ratio
  - Ballasting requirements are a function of buoyancy ratio. Partially buoyant concepts carry no ballast
  - Maneuver load factor = 1.3
  - Fixed useful load and fixed equipment weights are functions of mission requirements
  - Fly-by-wire control system
- Design
  - Wings for Megalifter sized for C_L = 0.55 (Optimum C_L for aspect ratio = 11.92)
  - Ratio of gas cell volume to hull volume (V_{GAS}/V_{HULL}):

Concept	V_{GAS}/V_{HULL}	
Conventional Rigid	.925	These values result from 6 inch cell clearance + 2.5% additional volume for miscellaneous equipment.
Helistat	.925	
Megalifter	.956	
Helipsoid	.950	
Dynairship	.957	
Conventional non-rigid	.905	Additional ballonet volume depending on design pressure altitude.

  - Configuration geometric characteristic specified in section 5.3
  - Design pressure altitude for hull size, prop/rotor size and engine size:

Mission	Design Pressure Altitude
Short Range	5000 ft ISA (1,524 m ISA)
Transcontinental	15000 ft ISA (4,572 m ISA)
Intercontinental	5000 ft ISA (1,524 m ISA)

- Aerodynamics
  - Hull drag and aerodynamics as discussed in section 5.4.2
  - Use "Generalized Method of Propeller Performance Estimation"[67] for propeller efficiency data
  - Use Boeing Vertol short method for rotor performance
  - Use rotor limits discussed in section 5.4.2.5 for rotor solidity sizing
- Stability and Control
  - Size empennage using the methods and guidelines discussed in section 5.4.2.7

ORIGINAL PAGE IS OF POOR QUALITY

The program contains size trend equations which reflect the variation of airship dimensions with gross lift and type, detailed statistical weight trends equations, routines for the sizing of engines, rotors and propellers to meet airframe requirements and routines to compute empennage size based upon neutral static stability.

CASCOMP can be used to study a large variety of conventional and hybrid lighter-than-air-craft. Figure 5-51 shows the configurations which can be analyzed. These are divided into conventional hull airships and lifting body hull airships, and are further divided into fully and partially buoyant designs.

The computer program flow diagram is shown in Figure 5-52. It is divided into five portions: Input data, a sizing routine, a weight routine, a mission performance routine and the output data. Gross lift, vehicle and propulsion system type, and nondimensionalized geometry are input to the program. Using these parameters, a vehicle is sized and weighed. Mission fuel is computed for the specified mission and the available payload is determined. CASCOMP output consists of airship geometry, component weight statement, available payload and mission time history. Appendix C of this report contains the User's Manual for CASCOMP and should be referred to for further details.

5.4.2.2 Parasite Drag Methodology

Parasite drag for the selected configuration have been estimated by the methods of Reference 66. This method utilizes a drag buildup technique, i.e., the parasite drags of each component of a vehicle is estimated and added together. Mutual interference, roughness, excrescence and other components of drag unique to each configuration are then added. This method has been demonstrated to work very well for conventional and V/STOL aircraft.

The drag of the six selected airship concepts is the sum of the hull, empennage, wing (if applicable) and drag increment due to fixed components. This is written as:

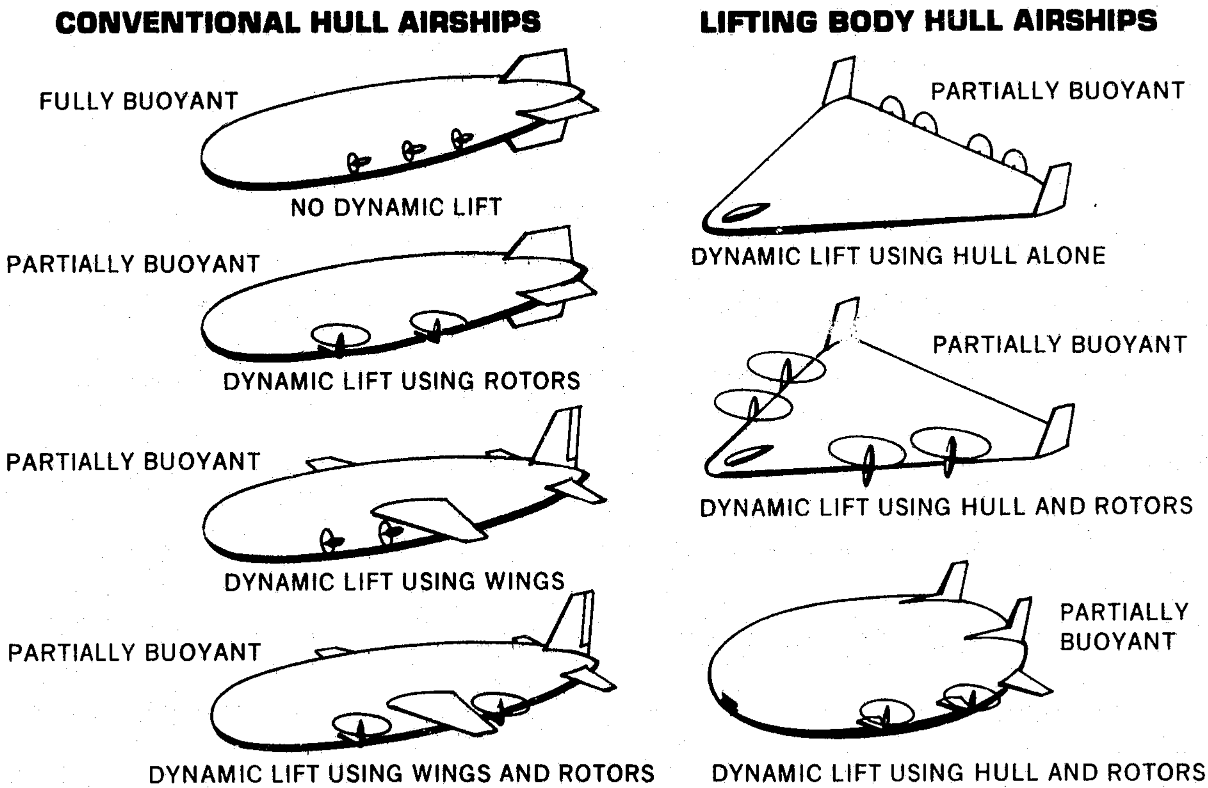


Figure 5–51. Applicable Configurations

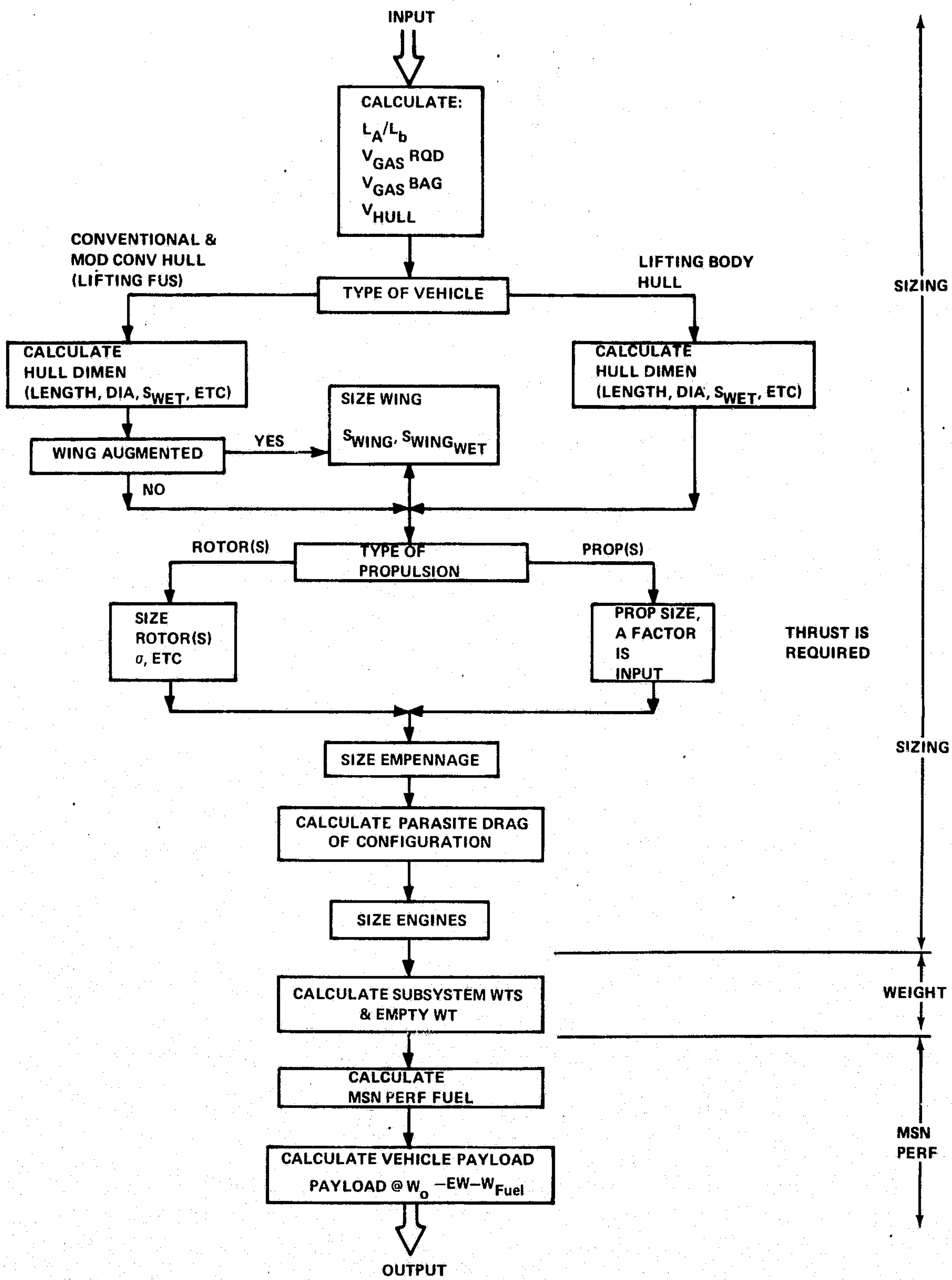


Figure 5–52. CASCOMP Flow Diagram

$$fe_{TOT} = fe_{HULL} + fe_{HT} + fe_{VT} + fe_{W} + \Delta fe$$

where:

fe_{TOT} is the total airship drag

fe_{HULL} is the hull drag

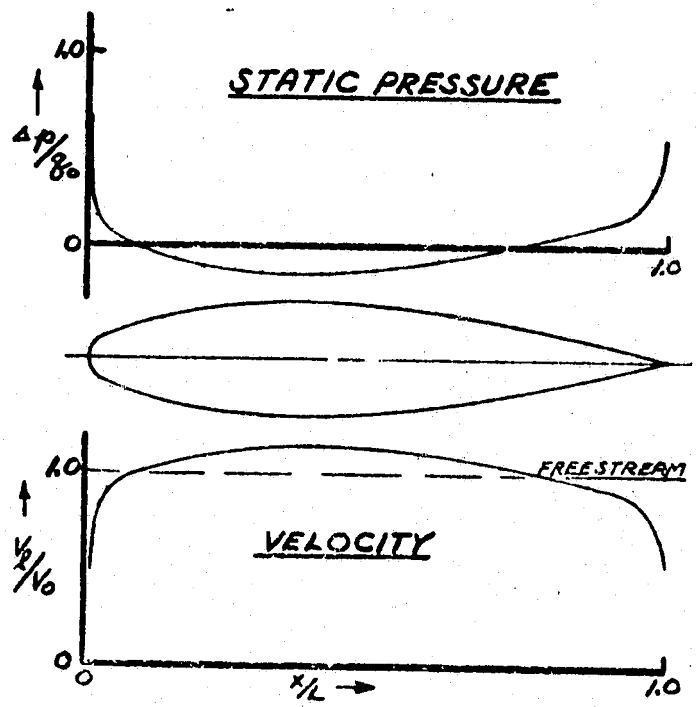
fe_{HT} is the horizintal tail drag

fe_{VT} is the vertical tail drag

Δfe is the drag increment due to fixed components

The equations which define each of these components[66] are given in the following paragraphs.

The hull drag for the conventional rigid, non-rigid, helistat and megalifter concepts is estimated by considering them to be streamlined bodies of revolution and adding factors and terms which account for deviations from the optimum. The pressure and velocity distribution plotted along the length of a streamlined body is generally as shown below (at zero lift). At the very front of the body, the static pressure is positive and the local velocity (V_ℓ) is less than free stream velocity (V_0). The local velocity rapidly becomes greater than free stream velocity for most of the length of the body. The difference between local and free stream velocity is referred to here as the supervelocity. The supervelocity results in an apparent increase of skin friction.



The boundary layer thickness decreases and the local skin friction increases in the negative pressure gradient on the front of the body. The positive pressure gradient following after the minimum pressure peak causes the boundary layer to grow at a faster rate than for a flat plate. The boundary layer thickens and the local shear force reduces until it is zero where the flow separates.

A further three dimensional effect (or drag increase above that for a flat plate) occurs when transforming a flat plate into a streamlined body. The cross-sectional area of the boundary layer is transformed into a circle, thinning it slightly and increasing the skin friction.

The above effects, including factors for roughness and excrescenes result in the following equation:

$$fe_{HULL} = \underbrace{(C_f\ A_W)_H}_{\text{Flat Plate Skin Friction}} \left[1+\underbrace{K_{3D}}_{\text{3-Dimensional Effects}}+\underbrace{R}_{\text{Discrete Roughness}} \right] (1+\underbrace{E}_{\text{Escrescences}})$$

where: C_f is the turbulent flat plate skin friction coefficient

A_W is the hull surface area

R is the discrete roughness = .05

E accounts for excrescenses = .07

Three dimensional effects (K_{3D}) are given by the following equation:

$$K_{3D} = \underbrace{.001\ (L/D)}_{\text{Friction increase due to wrapping a flat plate into a cylinder}} + \underbrace{1.5\ (D/L)^{3/2}}_{\text{Supervelocity}} + \underbrace{7\ (D/L)^{3}}_{\text{Pressure Drag}}$$

where L/D is the body fineness ratio.

It is evident from these equations that low fineness ratio bodies will have significantly more drag than more slender bodies.

Hull parasite drag for the Helipsoid and Dynairship concepts were estimated by treating them as wing surfaces. The general approach[66] is to first calculate the drag in isolated or free flow and add increments for excrescences and gaps. Mutual interference, if appropriate, is then added. The equation for the hull parasite drag when treated as a wing is as follows:

$$fe_{HULL} = \underbrace{C_f\ A_W}_{\text{skin friction}} \left[1 + \underbrace{K_{3D}}_{\text{3 dimensional effects}} + \underbrace{R}_{\text{roughness}}\right] (1 + \underbrace{E}_{\text{Excrescences}})$$

The terms of this equation are the same as those presented previously for conventional hulls, with the exception of the three dimensional effects. These are plotted in Figure 5-53 and imply that thick wings have high drag. Parasite drag for wings and tails for all LTA concepts are handled in a similar manner, except that a mutual interference drag, if appropriate, is added. Refer to Reference 66 for more details on this drag method. Increments in drag due to fixed components are then added to complete the drag estimate.

Drag coefficients calculated by the methods described above are then converted into the format specified by the CASCOMP User's Manual (Appendix C). A comparison of the results obtained by using this method with experimental airship results are shown in Table 5-XII. A correlation of the method with flight data from a C-130 transport is shown on Figure 5-54. As can be noted, the correlation of the method with experimental data is excellent.

5.4.2.3 Aerodynamic Lift and Induced Drag Methodology

The aerodynamic lift and induced drag of the lifting body concepts or the conventional hulled concepts have been estimated by the method described by Flax and Lawrence[73]. Lift is expressed as:

$$C_L = \frac{dC_L}{d\alpha}\alpha + C_{D_C}\alpha^2 \quad (C_L \text{ based on planform area})$$

where $\frac{dC_L}{d\alpha}$ represents the lift curve slope

α is the angle of attack in radians

C_{D_C} is the cross flow drag coefficient = 1.2

Induced drag is expressed as:

$$C_{D_i} = \frac{dC_L}{d\alpha}\alpha^2 + C_{D_C}\alpha^3$$

Figure 5-55 shows, for example, the lift curve slope and cross flow drag coefficient for conventional

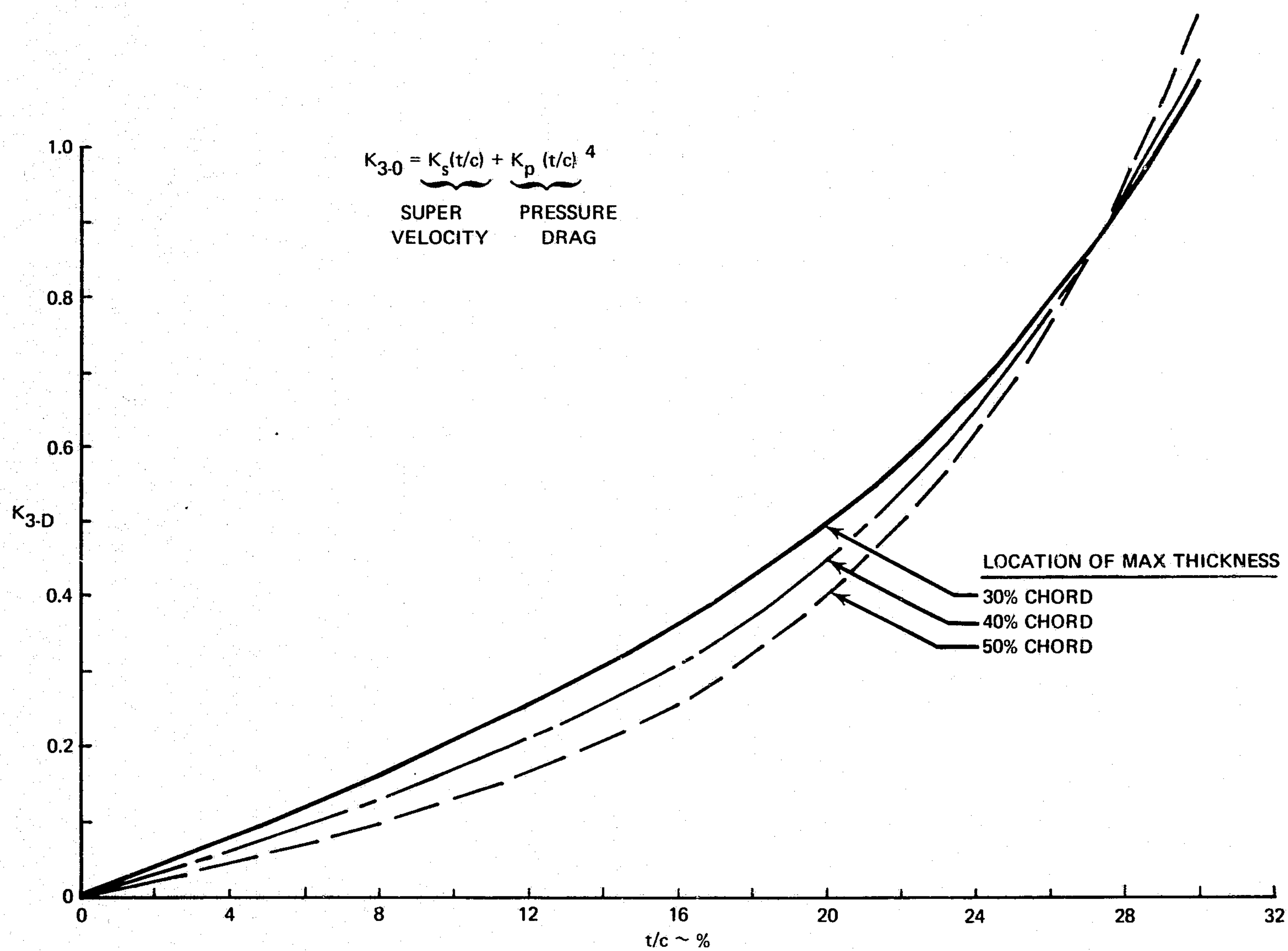


Figure 5–53. Three-Dimensional Effects for Wing and Tail Surfaces

Table 5–XII. Comparison of Drag Calculation with Test Data

COMPONENT	CALCULATED VALUES		TEST
	DRAG AREA ft^2 (m^2)	C_D	C_D
Hull	0.622 (0.0578)	.0192	-
Tail	0.085 (0.0079)	.0026	-
Cabin	0.031 (0.0029)	.0010	-
	0.738 (0.0686)	.0228	.021

Notes: 1. C_D is based on (Hull Volume)$^{2/3}$
2. Test data from NASA TND 1026

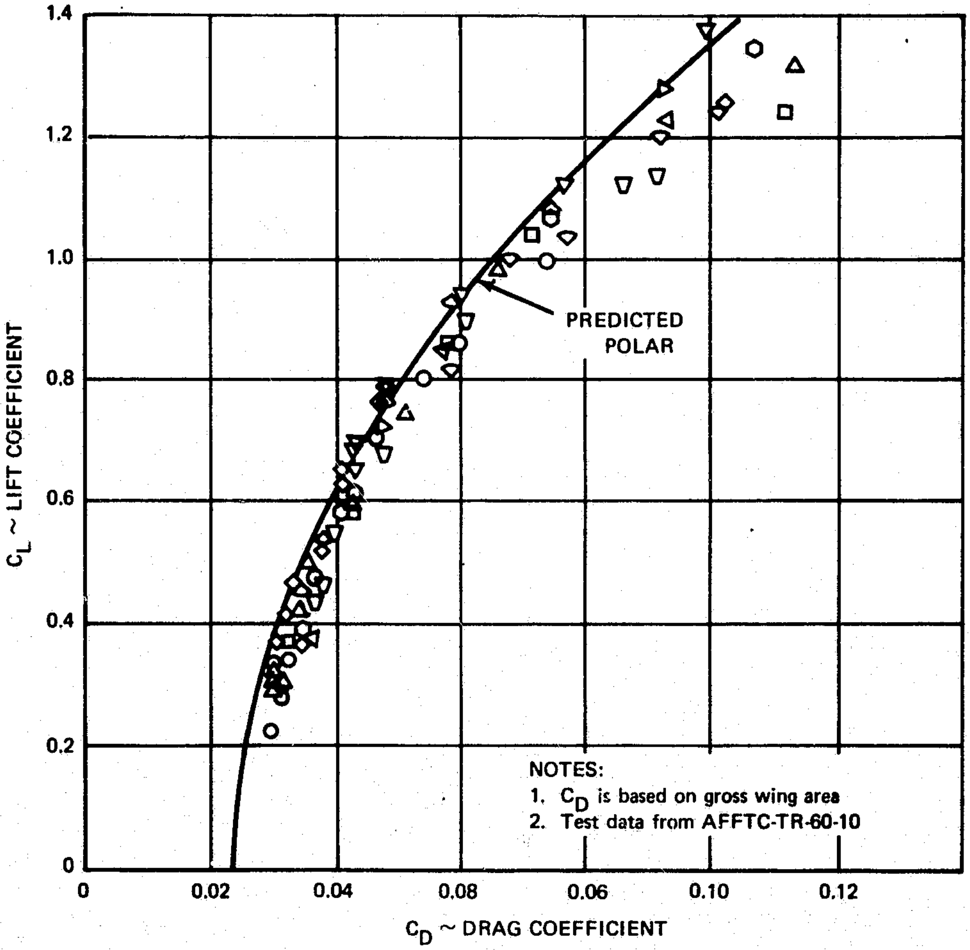


Figure 5–54. Comparison of Drag Calculations with C 130B Flight Test Data

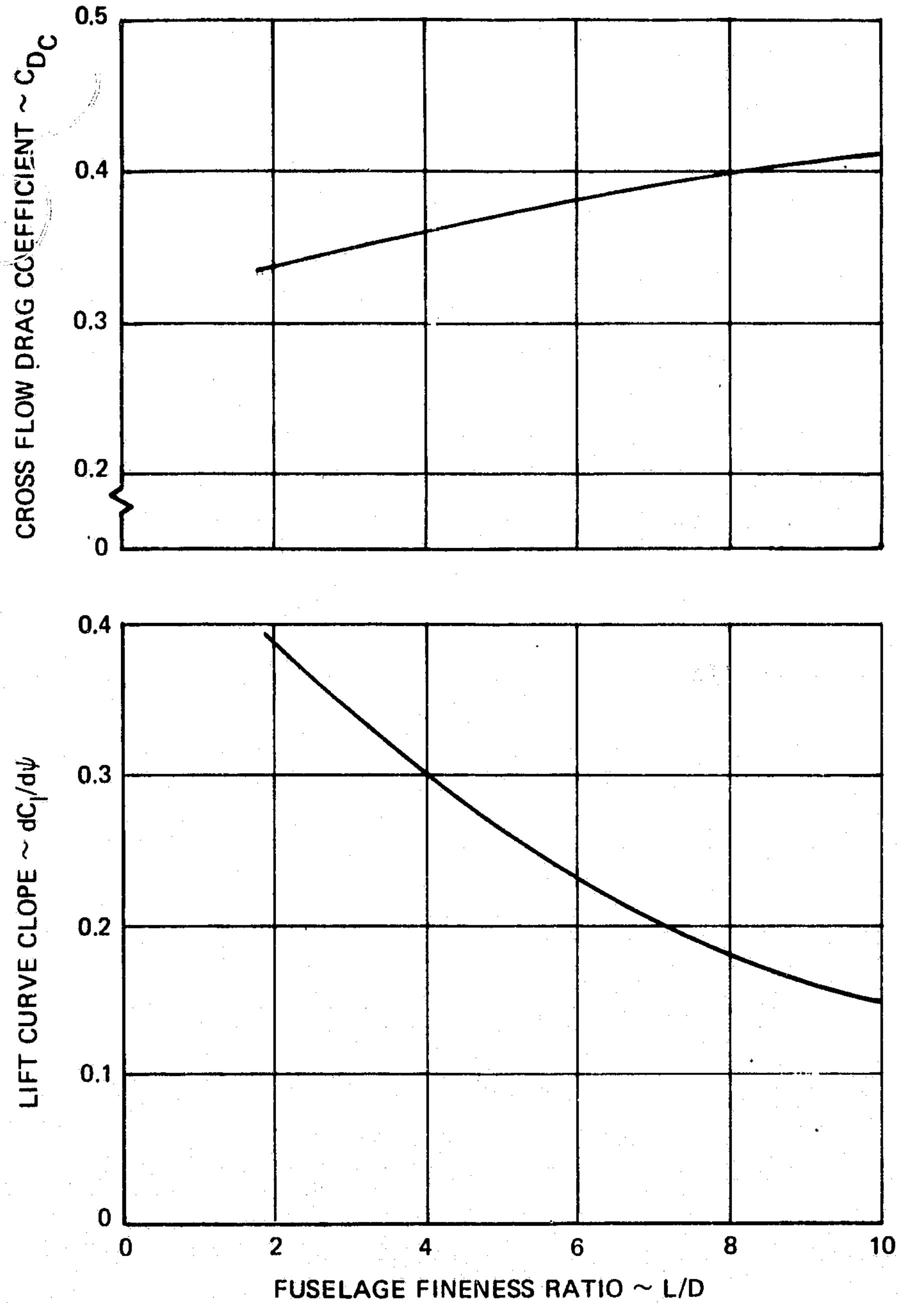


Figure 5–55. Lift Slope Curve and Cross Flow Drag Coefficient for Conventional Hulled LTA Concepts

hulled vehicles. Refer to Appendix C or Reference 73 for values of $dC_L/d\alpha$ and C_{D_C} for lifting body type hull planforms.

5.4.2.4 Propeller Performance Methodology

The propeller efficiency data used for the parametric analysis was obtained from the Hamilton Standard red book[67]. The data represents the locus of optimum efficiencies for a four bladed propeller with an activity factor of 140 per blade and an integrated lift coefficient of 0.5. The data is shown in Figure 5-56. No attempt was made to optimize the propellers for each of the propeller driven concepts, but it should be considered in future studies.

5.4.2.5 Rotor Methodology

Rotors are used as part of the partially buoyant Helistat configuration (described in Section 5.1). When analyzing the rotor, two factors must be considered: rotor performance over the advance ratio range of interest and the criterion used to determine rotor solidity.

The Boeing Vertol Company has developed a short form rotor performance method which is ideally suited to preliminary design studies.

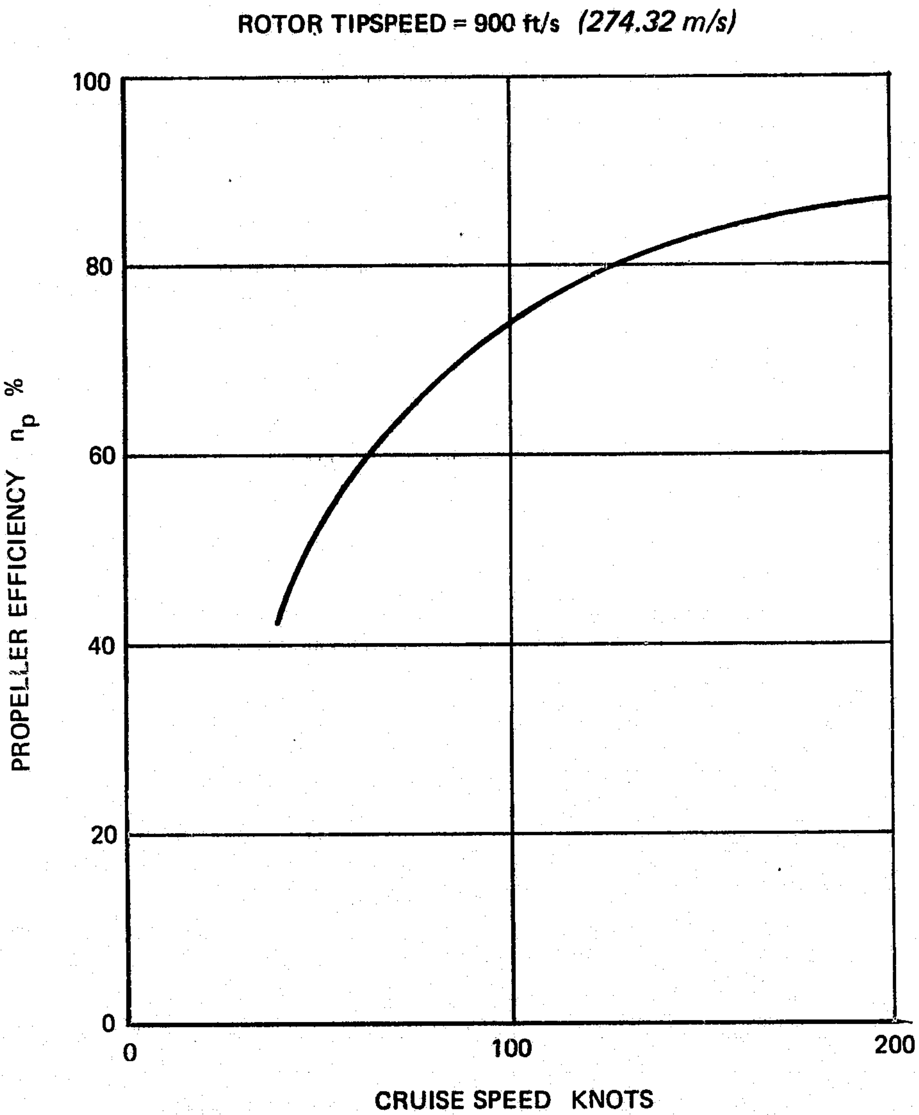
The short form aero rotor performance methodology is a combination of momentum theory and empirically derived factors. The four elements of the rotor power required are:

a) induced power (power required to generate lift)

b) profile power (power required to turn the rotor)

c) parasite power (power required to supply propulsive thrust in forward flight).

d) nonuniform downwash power (power correction due to nonuniform inflow and downwash effects in forward flight).



CONVERSION FACTOR: 1 kt = 0.514 m/s

Figure 5–56. Propeller Efficiency Data

Table 5-XIII is a summary of the major equations used in this methodology. A brief description of their applications follows:

In hover, the rotor power required is composed of only two parts, incuded and profile power. The induced power as represented by the equations in Table 5-XIII is a function of the variables K_{HOV} and C_T. K_{HOV} is the adjustment for nonuniform inflow and wake contraction effects and is a function of C_T, blade number, and blade twist.

The profile power is simple a function of the integrated blade drag coefficient (including compressibility effects) at a specified operating C_T/σ and blade solidity.

In cruise, the rotor power is composed of all four of the components listed initially. The induced power, as represented by the equations in Table 5-XIII, is a function of the quantities K_{IND}, C_T', and μ'. K_{IND} is the induced power adjustment factor which accounts for blade tip and other losses. Profile power is a function of the integrated blade drag coefficient (corrected for retreating blade stall and advancing blade compressibility effects) at specified operating conditions (C_T'/σ, μ, C_X), blade solidity, and advance ratio (μ). The parasite power is a function of the propulsive thrust required and the efficiency of the rotor in converting power into that propulsive thrust (in addition to providing lift). The nonuniform downwash (NUD) power is a correction which has been empirically derived from a comparison of uniform and nonuniform downwash rotor analyses.

In order to obtain a reasonable estimation of power required at very low advance ratios

Table 5—XIII. Short Form Aero Rotor Performance Equations Summary

MAIN ROTOR IN HOVER SUMMARY

$$RHP_{TOT} = \frac{\rho A V_T{}^3 C_{P_{TOT}}}{550}$$

where: $C_{P_{TOT}} = C_{P_{PRO}} + C_{P_{IND}}$

(PROFILE POWER) $C_{P_{PRO}} = C_{D_O} \frac{\sigma}{8} \quad (1 - X_c)$

(INDUCED POWER) $C_{P_{IND}} = .707 K_{HOV} \quad C_T{}^{3/2}$

$$C_T = \frac{\text{HOVER THRUST REQ'D}}{\rho A V_T{}^2}$$

$$A = \frac{\pi D^2}{4} N_{ROT}$$

$$X_c = 2r_{cutout}/D$$

MAIN ROTOR IN CRUISE FLIGHT SUMMARY

$$RHP_{TOT} = \frac{\rho A V_T{}^3 \; C_P}{550} \quad TOT$$

where: $C_{P_{TOT}} = C_{P_{PRO}} + C_{P_{IND}} + C_{P_{PAR}} + C_{P_{NUD}}$

(PROFILE POWER) $C_{P_{PRO}} = \frac{C_{D_o}\sigma}{8} \quad (1 + 4.65\mu^2) \quad (1 - X_c)$

(INDUCED POWER) $C_{P_{IND}} = \frac{K_{IND}}{2\mu'} \quad C'_T{}^2$

(PARASITE POWER) $C_{P_{PAR}} = \mu C_X \; (K_{PER})$

(NUD POWER) $C_{P_{NUD}} = \frac{2K_{NUD}C'_T\sigma}{B^2 \; (1 + D.L. \; \sin^2\varepsilon)}$

$$C'_T = \frac{L_{ROT}}{\rho A V_T{}^2} \; (1 + D.L. \; \sin^2\varepsilon)$$

$$C_X = \frac{X_{TOT}}{\rho A V_T{}^2} \qquad A = \frac{\pi D^2}{4} \quad N_{ROT}$$

$$\varepsilon = \tan^{-1} \; (2V / V \times 1.689)$$

$$v_i = V_T \sqrt{[(\mu^4 + C_T{}^2)^{1/2} - \mu^2]/2} \qquad K_{PER} + \frac{\mu PRI}{\mu PRR} = 1 + 12.8\mu^4$$

$$\mu' = \frac{\sqrt{(1.689V)^2 + v_i{}^2}}{V_T}$$

$$K_{NUD} = f(\mu)$$

$$D.L. = \frac{T}{W} - 1$$

($\mu < 0.1$) where neither normal cruise nor hover rotor characteristics totally describe the operating environment of the rotor, an empirical fairing technique is used. The method is based on the contracted induced wake angle ε:

$$\varepsilon = \tan^{-1}\left(2\, v_i/(1.689V)\right)$$

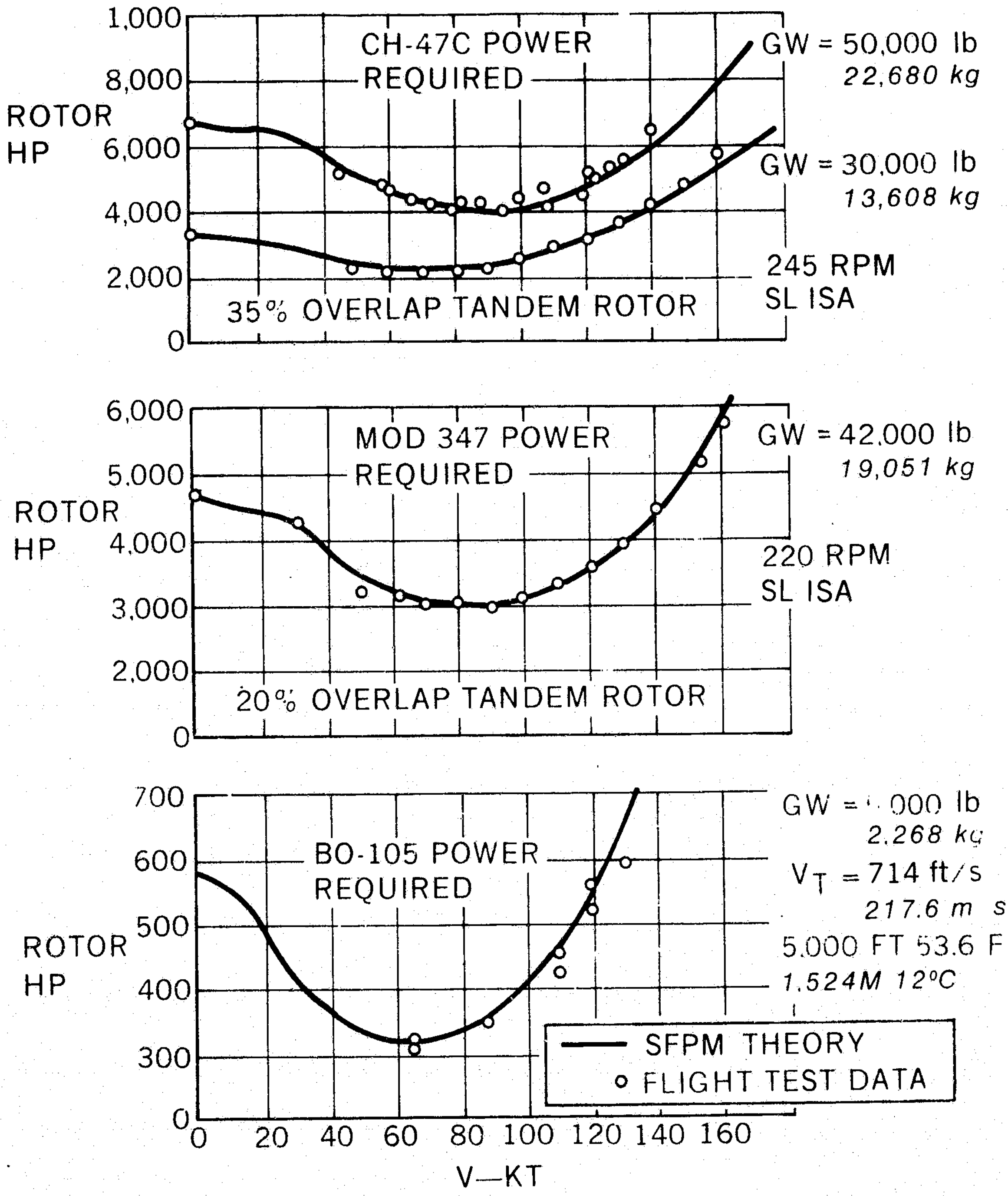
The relationship:

$$\sin^2 \varepsilon + \cos^2 \varepsilon = 1$$

is used to provide a smooth transition between hover and cruise characteristics for the affected coefficients while insuring that the resulting values will lie within the boundaries set by hover and cruise limiting conditions.

A detailed description of the equations used in this methodology can be found in Section 4.8 of Appendix C (Subroutine ROTPOW). The empirical factors used in this methodology are representative of the constant chord XCH-62 rotor system which uses high speed airfoil sections developed from NACA 6 series airfoil sections and optimized for maximum lift and low pitching moments. The empirical factors are listed in the block data of the CASCOMP program (Appendix C). Figure 5-57 shows the excellent comparison between the short form rotor methodology and flight test data.

The minimum rotor blade area, to avoid high alternating rotor loads, is calculated by using the rotor C_T/σ limit criterion shown in Figure 5-58. This criterion was established from wind tunnel test data for the UTTAS rotor system and is based on alternating pitch link loads for a hingeless rotor.



CONVERSION FACTOR: 1 kt = 0.514 m/s

Figure 5–57. Comparison of Short Form Aero Rotor Performance and Flight Test Data

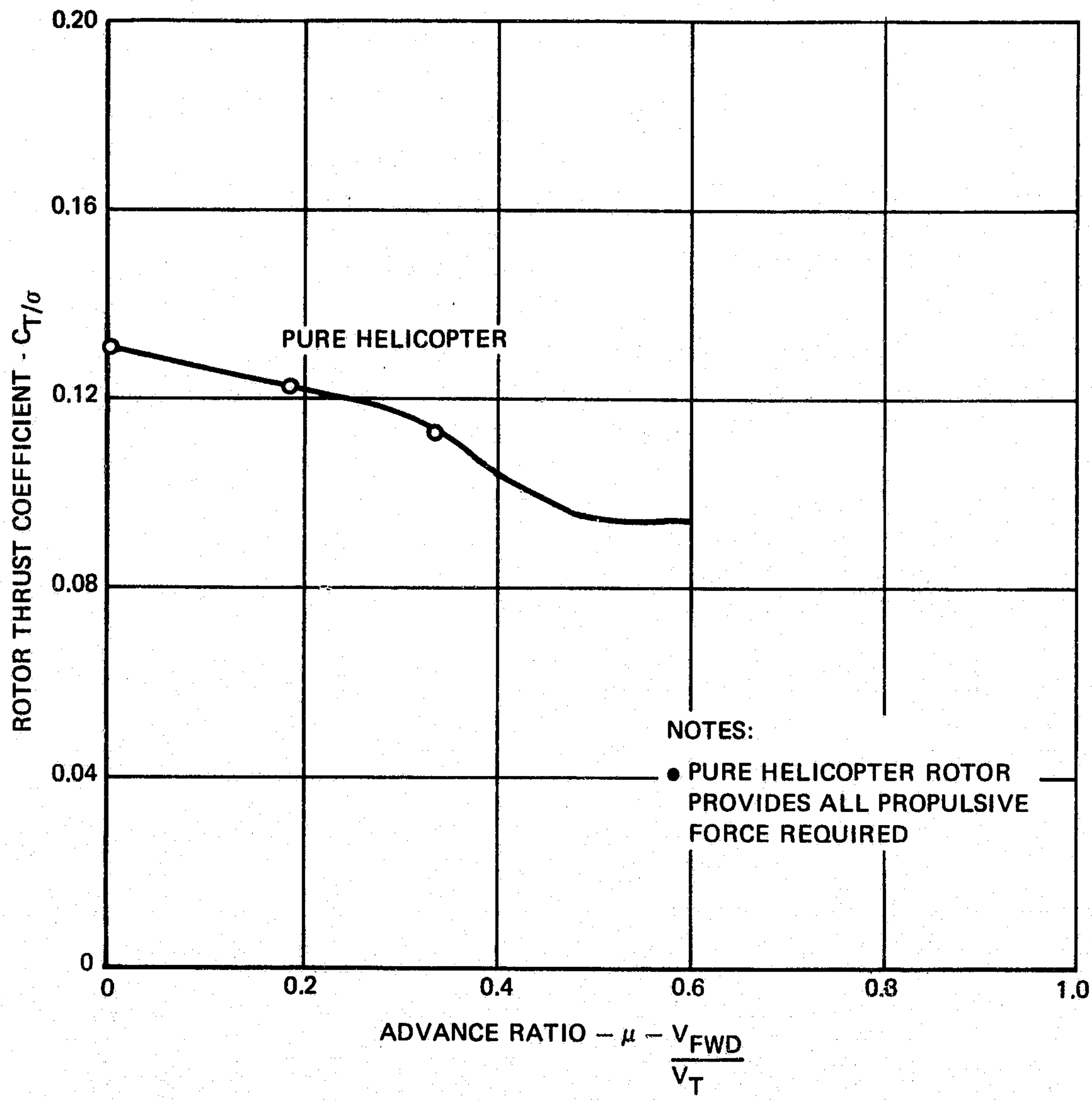


Figure 5–58. Helicopter Rotor Limits

5.4.2.6 Weight Methodology

The weights in this study are derived by (1) using methods previously developed by the Boeing Vertol weight unit for fixed wing aircraft and helicopters and (2) using methods developed specifically for airships. The methods are shown in the following discussions.

1. Wing Group

Wing weights are derived from the following equation:

$$W_W = 220a(k)^{0.585}$$

$$\text{where } k = \left[\frac{RmWx}{10^4}\right]\left[\frac{Sw}{10^2}\right]\left[\log \frac{b}{B}\right]\left[\frac{1+\lambda}{2Kr}\right]\left[\sqrt{N}\right]\left[\log_{10}V_D\right]\left[\log_{10}AR\right]$$

Legend

W_W = weight of wing, pounds
S_W = planform area of wing (taken from ℄ of aircraft), square feet
b = wingspan, feet
B = maximum fuselage width, feet
λ = taper ratio
N = ultimate load factor
V_D = dive velocity, knots
AR = aspect ratio
k_r = wing root thickness ÷ root chord
W_x = gross weight less wing and items on/in wing, pounds
R_M = relief term = $1 - \dfrac{(\text{dead wt in and on wing})\ (d_2)}{(W_G - \text{wing wt} - \text{wing fuel wt})\ (d_1)}$
d_1 = spanwise dimension from side of body to wing MAC, feet
d_2 = spanwise dimension from side of body to center of concentrated load, feet
W_G = takeoff gross weight, pounds
"a" = adjusting factor for type of wing (see Figure 5-59)

This wing weight equation represents the results of the wings analyzed in Figure 5-59. The 220 constant is an average for the spectrum of aircraft presented on the graph. The "a" factor adjusts the trend accordingly for the type of wing configuration being weighed. Typical examples of the value "a" are shown in Figure 5-59.

Figure 5-59 presents the weights of conventional wings designed primarily by airloads resulting from forward flight. The term R_MW_X in the trend equation indicates the magnitude of the resultant wing shear and bending loads located at the semispan center of lift in forward flight.

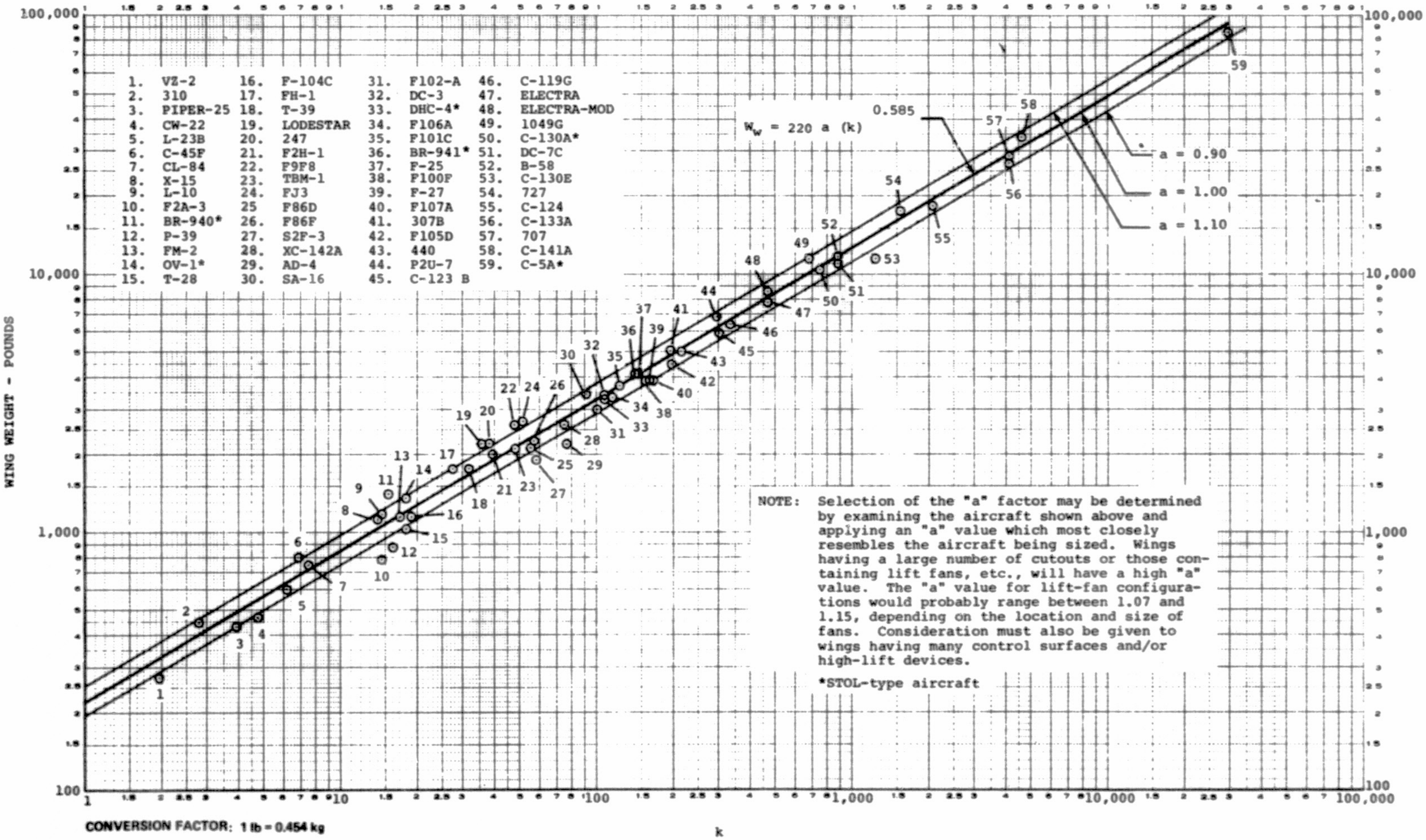


Figure 5–59. Wing Weight Trend

2. Rotors, Propellers

Main Rotors

The weight of a main rotor includes the combined weights of the blades and hub and hinge. The weights are derived from the following equations:

Blades (per rotor) $W_B = C_B\ a\ (k)^{0.438}$

Where

$$k = \frac{W_g}{10^4}\ LLF\ \frac{R^2}{100}\ \frac{R-r}{10}\ b\ c\ k_b\ \left(\frac{R}{k_d t}\right)^{1.6}$$

NOTE: The last term is a droop factor, used only if the result is greater than 1.

Hub and Hinge (per rotor) $W_{HH} = C_H\ a\ (k)^{0.358}$

Where

$$k = W_b\ R\ N_R^{\ 2}\ P_R\ r^{\ 1.82}\ b^{\ 2.5}\ k_{amd} \times 10^{-11}$$

Legend

W_B = blade weight per rotor (including root end fitting) - lb or kg
W_{HH} = hub weight per rotor, - lb or kg
C_B = 44 (English System), 226.1 (International System)
C_H = 61 (English System), 122. (International System)
a = adjustment factor
W_g = design gross weight per rotor (X 0.6 for tandem) - lb
LLF = design limit load factor at dgw
R = rotor radius - ft or m
r = rotation to blade attachment - ft or m
c = blade chord - ft or m
b = number of blades per rotor
t = maximum blade thickness at 25%R - ft or m
k_b = rotor type factor: 1.00 articulated, 2.2 hingeless or teetering
k_d = droop constant: 1000 tandem, 1200 single rotor
W_b = blade weight per blade (including root end fitting) - lb or kg
N_r = rotor rpm
P_r = takeoff power X (0.6 for tandem) per rotor - hp
k_{amd} = a x m x d
a = design concept: 0.53 hingeless, 1.00 other
m = material: steel = 1.00, titanium = 0.54
d = development stage: early = 1.0, developed = 0.62

In the trend equations the constants 44(blade trend) and 61 (hub and hinge trend) represent the average for the rotor weights presented in Figure 5-60 and 5-61. The blade weights are most representative of the all metal blades. The adjustment factor a is used to adjust when special design features are considered, such as high modulus materials (boron, graphite, etc.) or special features associated with the hub and/or hinge.

Propeller

The weight of propellers is derived from the following equation:

$$W_P = C_P \quad a\ (k)^{0.67},$$

Where

$$k = \left[r\right]^{0.25} \left[\frac{Hpr}{100}\right]^{0.5} \left[\frac{Vtl}{100}\right] \left[\frac{R.b.c.}{10}\right]$$

Legend

W_R = weight of rotor or propeller - lb or kg

R = rotor radius - ft or m

b = number of blades per rotor

c = blade chord (average) - ft or m

HP_r = horsepower (xmsn limit per rotor)

V_{tl} = design limit tip speed - ft/sec or m/sec

r = center line of rotation to average blade attachment point - ft or m

a = adjusting factor for type of system (see Figure 5-62)

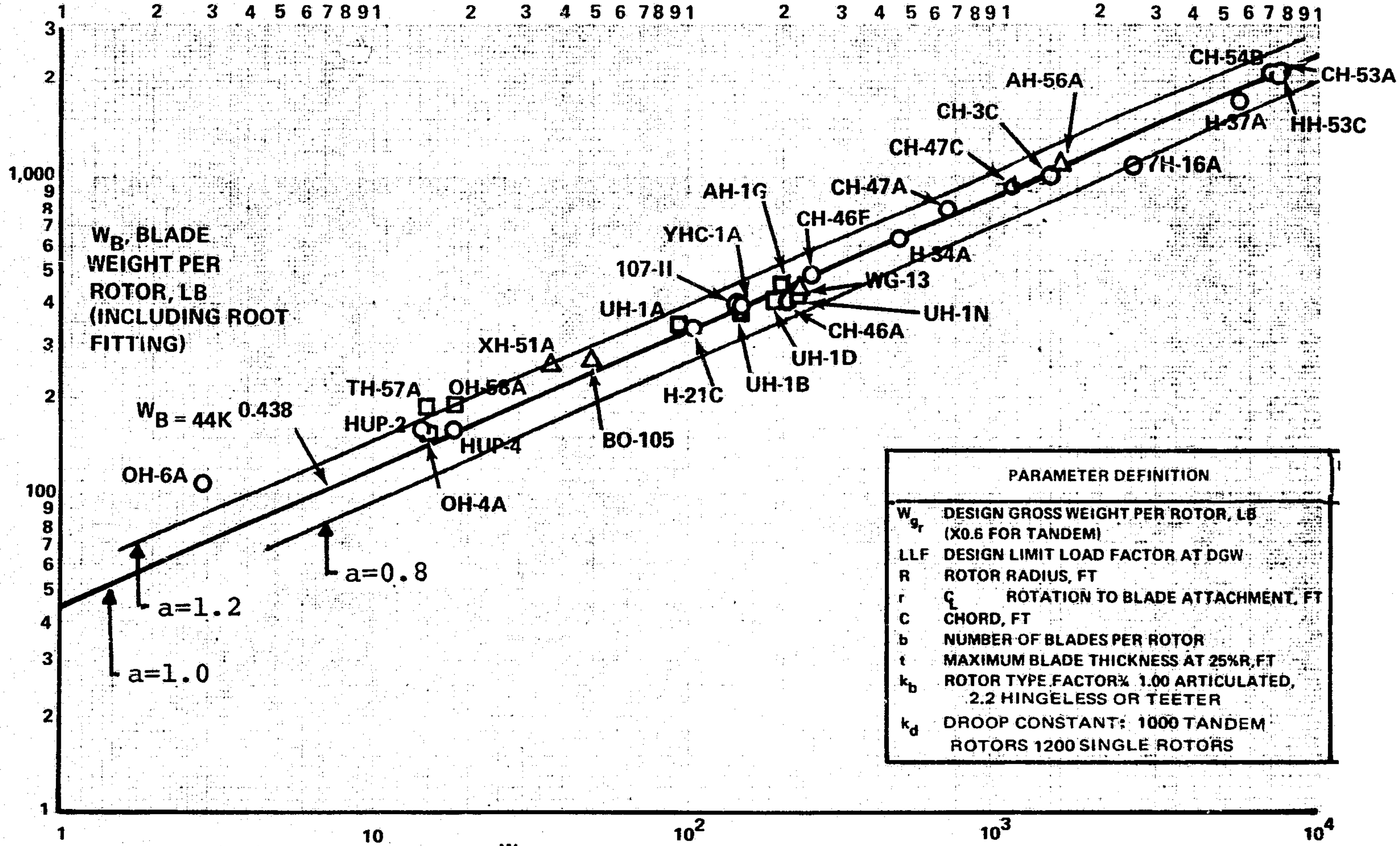
C_P = 14.2 (English System), 38.6 (International System)

In the trend equation the constant k is the average for the various rotor group weights presented in Figure 5-62. The expression a is the adjustment factor for the type of system.

3. Tail Group

The weights of the horizontal and vertical tails were determined from available statistical data from other lighter than air aircraft.

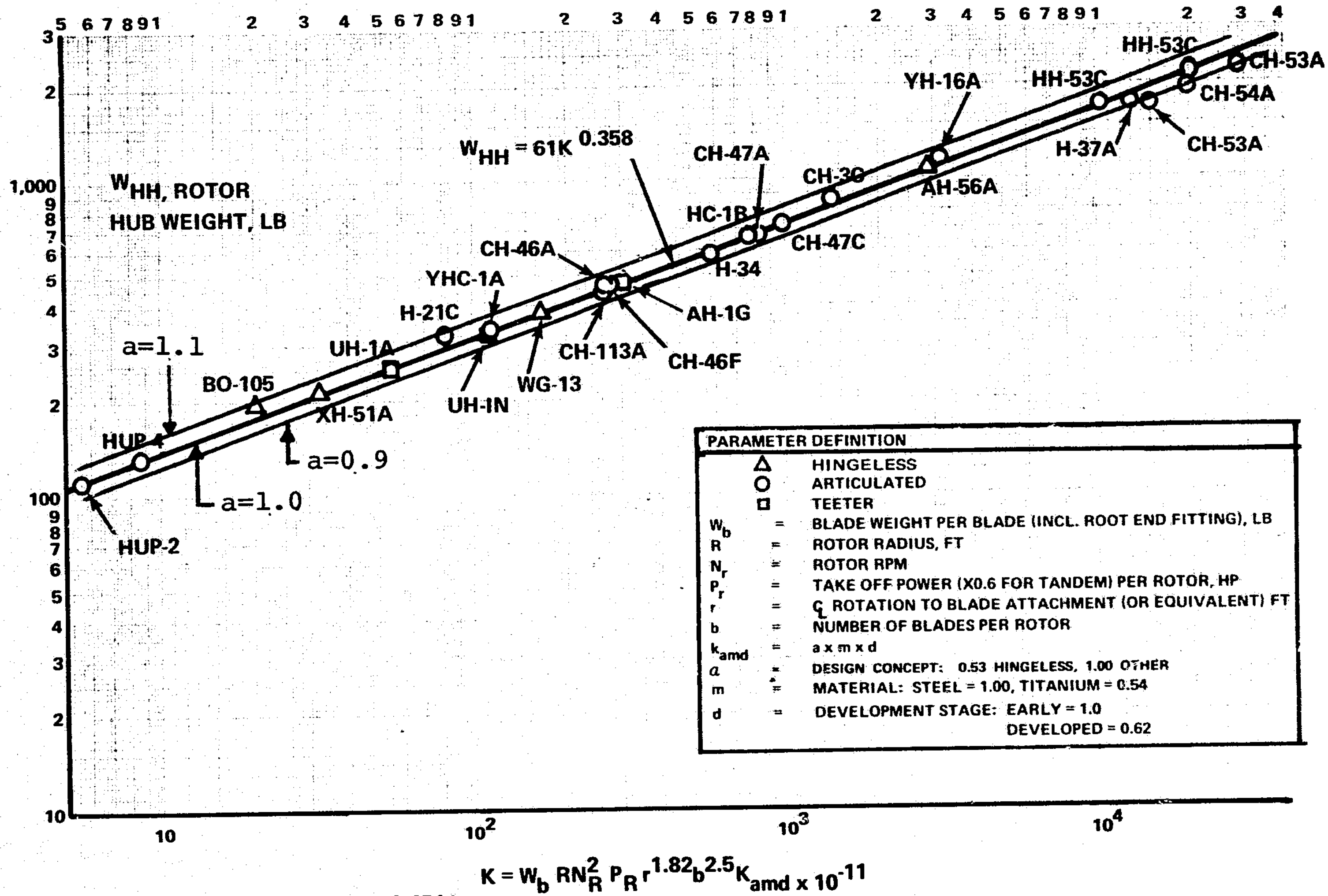
	Tail Weight lb/ft^2	Tail Weight Kg/M^2
Good year "K"	0.75	3.67
ZPG-2	1.09	5.32
ZPG-3W	1.03	5.03
ZRS-5 (Macon)	0.99	4.84



$$K = \frac{W_{g_R}}{10^4} \; LLF \; \frac{R^2}{100} \; \frac{(R-r)}{10} \; b\,C\,k_b \left[\frac{R^{1.6}}{k_d\,t}\right]$$ (USE [TERM] IF GREATER THAN 1.00

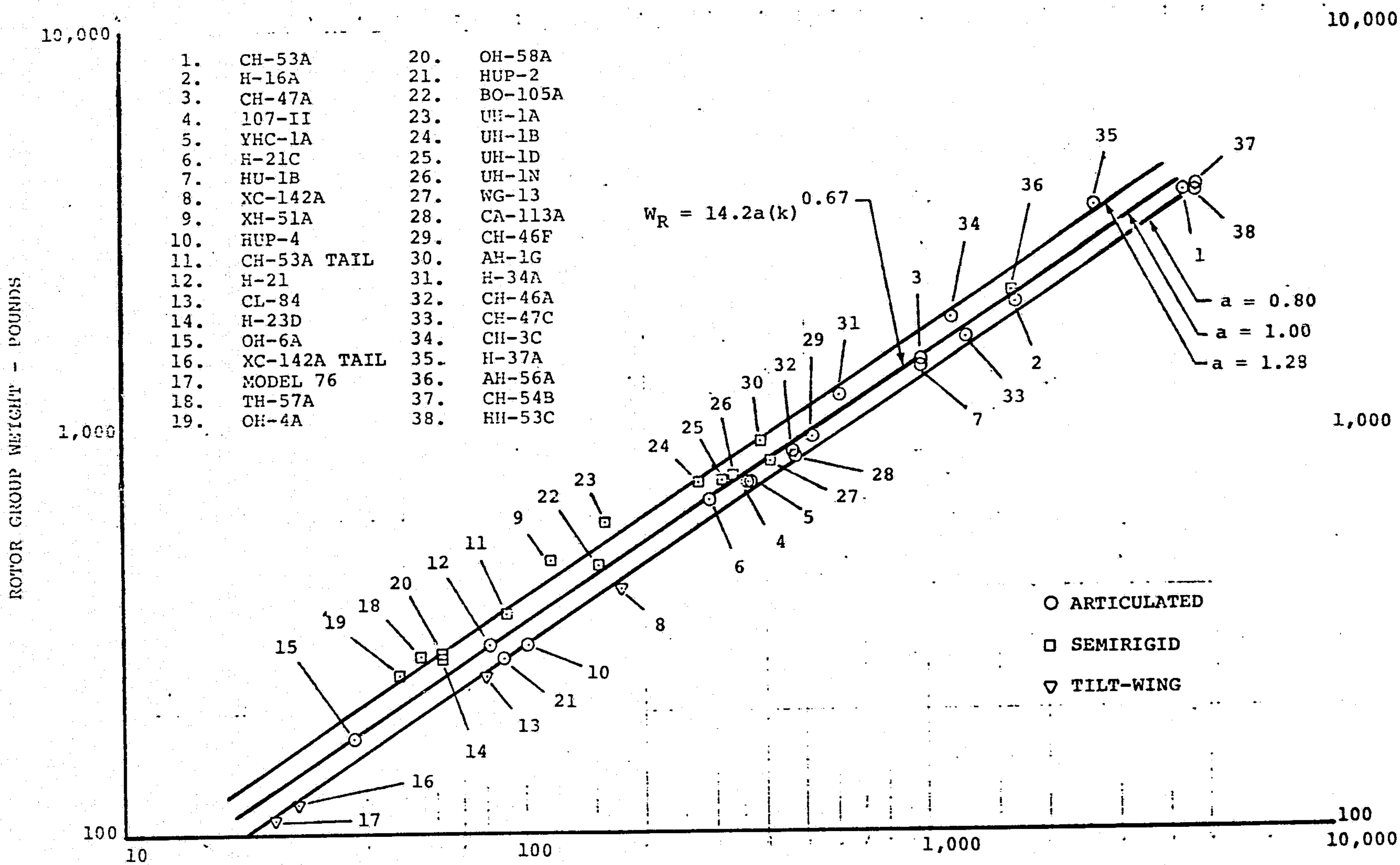
CONVERSION FACTOR: 1 lb = 0.454 kg

Figure 5–60. Rotor Blade Weight Trend



CONVERSION FACTOR: 1 lb = 0.454 kg

Figure 5–61. Rotor Hub and Hinge Weight Trend



CONVERSION FACTOR: 1 lb = 0.454 kg

Figure 5–62. Propeller Group Weight Trend

Adjusting the above for type and speed the following were determined.

		English System		International System	
Rigid:					
	50 Kt	Wt:	1.084 ST	25.7 m/sec	$W_T = 5.29 \times ST$
	100 Kt	Wt:	1.084 ST	51.4 m/sec	$W_T = 5.29 \times ST$
	200 Kt	Wt:	1.216 ST	102.9 m/sec	$W_T = 5.93 \times ST$
Non-Rigid:					
	50 Kt	Wt:	1.03 ST	25.7 m/sec	$W_T = 5.03 \times ST$
	100 Kt	Wt:	1.03 ST	51.4 m/sec	$W_T = 5.03 \times ST$
	200 Kt	Wt:	1.16 ST	102.9 m/sec	$W_T = 5.66 \times ST$

Legend

Wt = Total Tail Weight, Including Covering,
ST = Total Tail Planform Area, Square Feet

4. Hull Structure

Hull structure weights are derived using the following equation from Figure 5-63:

$$W_H = C_H \quad aK^{0.685}$$

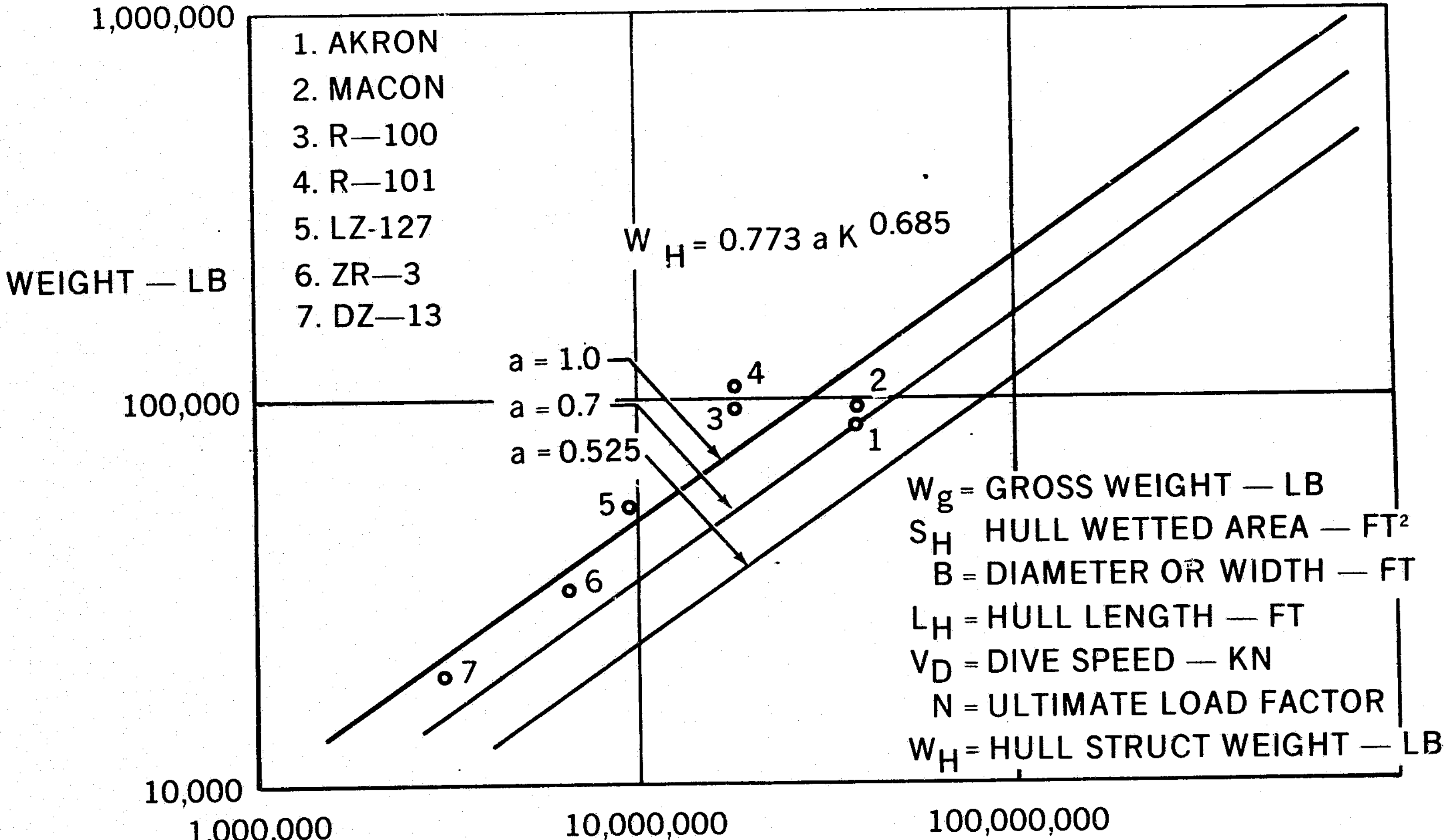
$$\text{where } K = \left[\frac{W_g}{10^4}\right]^{0.7} \left[\frac{S_H}{10^3}\right] \left[B\right] \left[L_H\right]^{-0.5} \left[L_{OG} V_D\right] \left[N\right]^{0.3}$$

Legend

W_H	=	Hull structure weight (not including covering), lb or kg
W_g	=	Gross Weight, lb or kg
S_H	=	Hull wetted area, square feet or square meters
B	=	Hull diameter or width, whichever is greater, ft
L_H	=	Hull length, feet or meters
V_D	=	Dive speed, Kts or m/sec
N	=	Ultimate load factor
a	=	Adjusting factor for state-of-the-art
C_H	=	0.773 (English System), 9.9 (International System)

Frame, Girder Structure

This equation represents the results of the hulls analyzed in Figure 5-63. The 0.773 constant is the average for the aircraft shown. The Macon, however, is shown at 70% below this line and to account for the advancement in technology and materials (see Fig. 20) it is further reduced by another 25%.



$$K = \left(\frac{W_g}{10^4}\right)^{0.7} \left(\frac{S_H}{10^3}\right) (B)\ (L_H)^{0.5}\ (\mathrm{Log}_{10} V_D)\ (N)^{0.3}$$

CONVERSION FACTOR: 1 LB = 0.454 KG

Figure 5–63. Hull Structure, Rigid Airships

The "a" factor is therefore 0.525 for this study. Outer covering is not included and is considered separately.

5. Outer Fabric Covering

The weight of the outer covering for a rigid frame, girder type airframe is based on fabric weight established by ILC Dover,Dover Delaware acting as consultants in this study (see Appendix C). These weights are:

English System	Weight	International System Velocity	Weight
50 Kt	= .276 lb/square yard	25.7 m/sec	.150 kg/m^2
100 Kt	= .276 lb/square yard	51.4 m/sec	.150 kg/m^2
200 Kt	= .231 lb/square yard	102.9 m/sec	.179 kg/m^2

Adjusting these basic weights by adding anti-flutter wires, a rigid nose cone for the 200 Kt condition and applying a 1.2 installation factor as determined from previous covering installations, the weights are:

English System		International System	
50 Kt	= 0.378 lb/square yard	25.7 m/sec	.205 kg/m^2
100 Kt	= 0.378 lb/square yard	51.4 m/sec	.205 kg/m^2
100 Kt	= 0.981 lb/square yard	102.9 m/sec	.527 kg/m^2

6. Main Envelope, Non-Rigid

The weight of the non-rigid main envelope is based on the fabric weight established by ILC Dover, Dover, Delaware acting as consultants in this study (see Appendix C). Their equations are:

English System

50 Kt $W_{ENF} = S_{WET}\ (1.552 \times 10^{-3}\ D + .274)$

100 Kt $W_{ENF} = S_{WET}\ (4.792 \times 10^{-3}\ D + .274)$

200 Kt $W_{ENF} = S_{WET}\ (1.776 \times 10^{-2}\ D + .274)$

International System

25.7 m/sec $= S_{WET}(2.762 \times 10^{-3} D + .149)$

51.4 m/sec $= S_{WET}(8.527 \times 10^{-3} D + .149)$

102.9 m/sec $= S_{WET}(3.16 \times 10^{-3}\ D + .149)$

Legend

W_{ENF} = Weight of non-rigid envelope fabric, lb or kg
S_{WET} = Wetted area of envelope, square yard or square meter
D = Maximum diameter, feet or meter

Adjusting these equations for ZPG-2 and ZPG-3W type bow stiffening and applying a 1.23 installation factor as determined from ZPG-2 and ZPG-3W the equations are:

English System

50 Kt $W_{EN} = S_{WET}\ (0.0019\ D + 0.447)$
100 Kt $W_{EN} = S_{WET}\ (0.0060\ D + 0.78)$
200 Kt $W_{EN} = S_{WET}\ (0.0219\ D + 2.119)$

International System

25.7 m/sec $W_{EN} = S_{WET}\ (.0034\ D + .237)$
51.4 m/sec $W_{EN} = S_{WET}\ (.0105\ D + .336)$
102.9 m/sec $W_{EN} = S_{WET}\ (.0389\ D + 1.966)$

Legend

W_{EN} = Weight of main envelop, lb, kg
S_{WET} = Wetted area of envelope, square yards or square meters
D = Maximum diameter, feet or meters

7. Ballonets

The weight of the ballonets are based on the weights derived by ILD Dover, Dover, Delaware, acting as consultants in this study (see Appendix C). Their basic equation is:

English System

$W_{BLNT} = 0.15\ S_{WET}$

International System

$W_{BLNT} = .081\ S_{WET}$

Legend

W_{BLNT} = Weight of ballonets, lbs or kg
S_{WET} = Wetted area of main envelope, square yard or square meter

Adjusting these equations fo ZPG-2 and ZPG-3W type installation factors, the equation is:

English System

$W_{BLNT} = 0.33\ S_{WET}$

International System

$W_{BLNT} = 0.178\ S_{WET}$

Legend

W_{BLNT} = Weight of ballonets, lb or kg
S_{WET} = Wetted area of main envelope, square yards or square meters

The installation factor includes airlines, pressure systems, etc.

8. Gas Cells

The weights of the gas cells are based on equations derived by ILC Dover, Dover, Delaware acting as consultants in this study (see Appendix C). These basic equations are:

English System

Conventional Rigid	$W_{GC} = .358\ S_{WET} + .894\ D^2_{MAX}$
Megalifter	$W_{GC} = .358\ S_{WET} + .894\ D^2_{MAX}$
Helistat	$W_{GC} = .358\ S_{WET} + .894\ D^2_{MAX}$
Helipsoid	$W_{GC} = .358\ S_{WET} + .125\ S^2_{MAX}$
Dynairship	$W_{GC} = .358\ S_{WET} + .113\ S^2_{MAX}$

International System

$$W_{GC} = 0.194\ S_{WET} + 4.355\ D^2_{MAX}$$
$$W_{GC} = 0.194\ S_{WET} + 4.355\ D^2_{MAX}$$
$$W_{GC} = 0.194\ S_{WET} + 4.355\ D^2_{MAX}$$
$$W_{GC} = 0.194\ S_{WET} + 0.609\ S^2_{MAX}$$
$$W_{GC} = 0.194\ S_{WET} + 0.550\ S^2_{MAX}$$

Gas Cell Netting = 0.0625 lb/sq yd

Legend

W_{GC} = Weight of gas cell, lb or kg
S_{WET} = Hull wetted area, squared yard or square meter
D_{MAX} = Maximum diameter of hull, feet or meter
S = Maximum Span, feet or meter

An installation factor of 1.05 times the weight of the basic gas cell and netting weight has been determined from ZR-1 (Shenandoah) and ZR-3 (Los Angeles). This factor provides primarily for the weight of the valving systems.

Applying this factor, the equations are:

English System

Conventional Rigid	$W_{GC} = 0.441\ S_{WET} + 0.939\ D^2_{MAX}$
Megalifter	$W_{GC} = 0.441\ S_{WET} + 0.939\ D^2_{MAX}$
Helistat	$W_{GC} = 0.441\ S_{WET} + 0.939\ D^2_{MAX}$
Helipsoid	$W_{GC} = 0.441\ S_{WET} + 0.131\ S^2_{MAX}$
Dynairship	$W_{GC} = 0.441\ S_{WET} + 0.119\ S^2_{MAX}$

International System

$$W_{GC} = 0.239\ S_{WET} + 4.572\ D^2_{MAX}$$
$$W_{GC} = 0.239\ S_{WET} + 4.572\ D^2_{MAX}$$
$$W_{GC} = 0.239\ S_{WET} + 4.572\ D^2_{MAX}$$
$$W_{GC} = 0.239\ S_{WET} + 0.639\ S^2_{MAX}$$
$$W_{GC} = 0.239\ S_{WET} + 0.577\ S^2_{MAX}$$

Legend

W_{GC} = Weight of gas cells, lb or kg
S_{WET} = Hull wetted area, square yards or square meter
D_{MAX} = Maximum diameter, feet or meter
S = Maximum span, feet or meter

9. Landing Gear

The landing gear weights are based primarily on those of the ZPG-2 and ZPG-3W aircraft 1.3% of gross weight. Since studies of partially buoyant aircraft may be conducted, the weights are determined as:

$$W_{LG} = 1.3\% \text{ Buoyant Weight} + 2.0\% \text{ Non Buoyant Weight}$$

therefore:

At 100% Buoyant, W_{LG} = 0.013 G.W.
90% Buoyant, W_{LG} = 0.0137 G.W.
75% Buoyant, W_{LG} = 0.0148 G.W.
55% Buoyant, W_{LG} = 0.0162 G.W.
35% Buoyant, W_{LG} = 0.0176 G.W.

Legend

W_{LG} = Weight of Landing Gear, Lb or kg
G.W. = Gross Weight, Lb or kg

10. Engine Section

The engine section consists of engine mounts, engine nacelle and engine or rotor pylons. The weight is determined by:

Otto, Diesel, Brayton, Rankine-Petroleum Engine Cycles
$W_{ES} = 2.5\ W_E$
Rankine-Nuclear, Stiring Engine Cycles $W_{ES} = 1.0\ W_E$

Legend

W_{ES} = Weight of Engine Section, Lb or kg
W_E = Weight of Engines, Lb or kg

11. Power Source (Engines, Etc.)

The various power source systems are discussed in section 5.2.1. The weights of these are determined through the following:

Engine Cycle	Size SHP	Specific Weight Lb/SHP	Kg/SHP
Otto	<1000	1.5	0.68
	1000-5000	0.7	0.32
Diesel	<1000	1.5	0.68
	1000-5000	0.7	0.32
Brayton-Petroleum Fuel	<1000	0.24	0.11
	1000-30,000	0.15	0.07
Brayton-Nuclear Fuel	5000-10,000	2.2	1.00
Rankine-Petroleum Fuel	<1000 1000-30,000	1.0	0.45
Rankine-Nuclear Fuel	5000-10,000	3.0	1.36
Stirling	<1000	6.0	2.72

These systems are discussed in section 5.2.1.

12. Engine Installation

The engine installation consists of exhaust systems, engine cooling, engine controls, starting systems, and lubricating systems. For this study they were established in terms of percent of engine weight.

	% Engine Weight
Exhaust Systems	2.8
Cooling	7.0
Controls	5.6
Starting	6.7
Lubricating	4.9
Total	27.0

13. Fuel System

The fuel system weight has been established at 7% of the fuel weight.

14. Drive System

The weight of the drive system (primary and auxiliary) including gear boxes, accessory drives, shafting, oil, supports, etc., is derived from the following equation:

$$W_{DS} = C_D \cdot a \, (k_D)^{0.67},$$

Where

$$k_D = \left[\frac{P_X}{N_R} \right] \left[Z \right]^{1/4} \left[K_t \right]$$

Legend

W_{DS} = weight of the drive system lb or kg

P_X = drive system horsepower rating (tandem rotor P_X = 1.2 X takeoff rating)

N_R = rotor rpm at takeoff

Z = number of stages in main rotor drive

K_t = configuration factor; 1.00 for single rotor, 1.30 for tandem

a = drive system correcting

C_D = 250 (English System), 113.7 (International System)

The drive system adjusting factor a is used to account for type, number of boxes, special features, etc., included in the drive system. Figure 5-64 gives typical examples of the a factor.

15. Flight Controls

The flight controls consist of cockpit or control car controls, airship controls, wing controls, rotor rotating controls, rotor system controls, tilting mechanism and controls, ballast and ballast system and autopilot. Fly by wire systems whereever applicable are utilized.

An equation which includes a combined series of weight trend expressions applicable to most any type of airship configuration is presented below. It includes factors which can be isolated and applied to the particular vehicle being analyzed. A description of the items comprising each of the control subgroups is included.

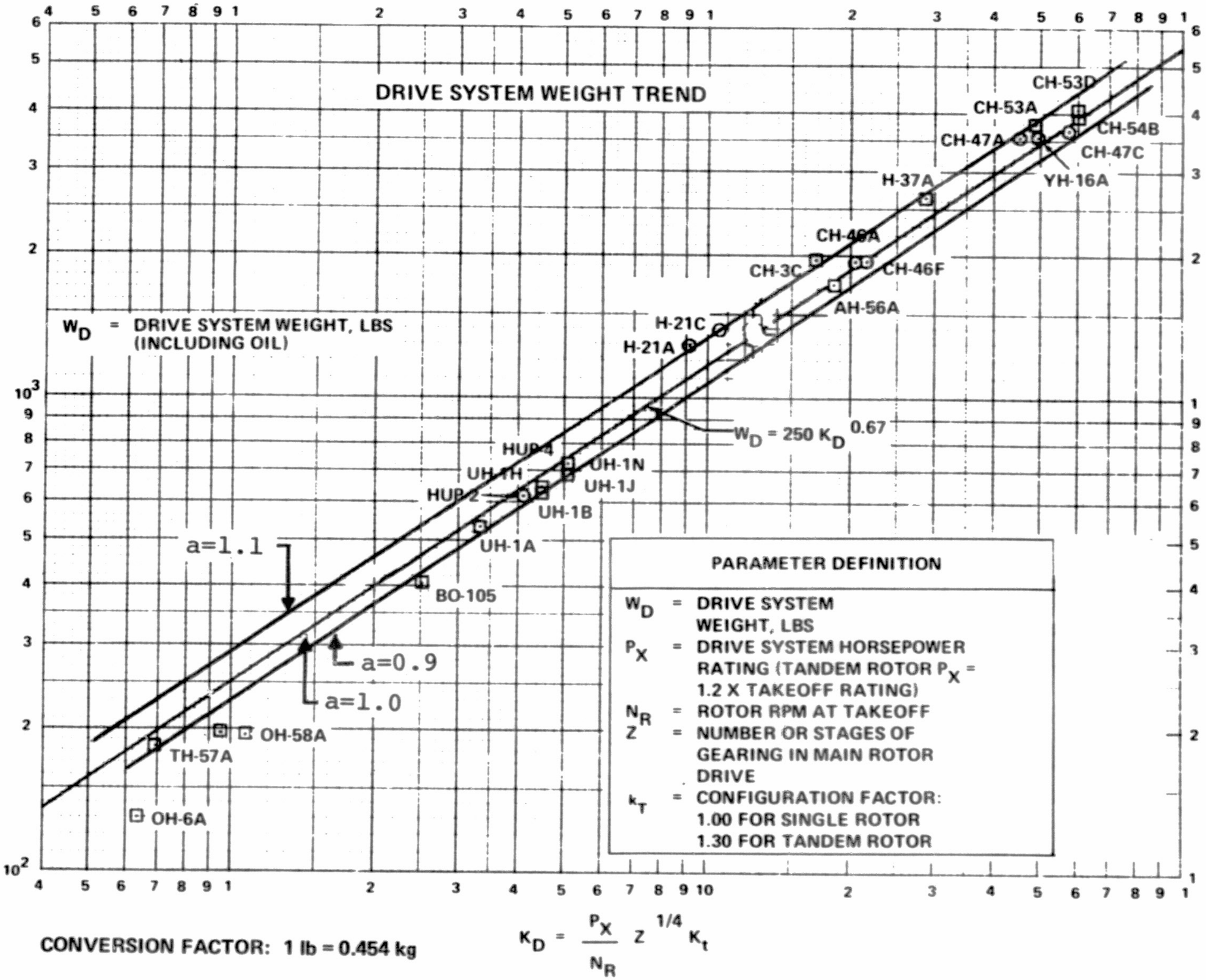


Figure 5–64. Drive System Weight Trend

$$W_{FC} = k_{cc}a\left[\frac{W_g}{1000}\right]^{0.41} + k_{RC}a\left[C\sqrt{\frac{R\,W_B}{1000}}\right]^{1.11} + k_{SC}\,a\left[\frac{W_R}{100}\right]^{0.84}$$

$$+ k_{FW}\,a\left[W_g\right] + k_{TM}a\left[W_g\right] + k_{SAS} + K_{RCA}a\left[W_R\right]$$

$$+ k_{SCA}a\left[\frac{W_R}{100}\right]^{0.84} + K_{BAL}a\left[W_g\right] + K_{AS}\,a\left[W_g\right] + K_{MISC}$$

Legend

W_{FC} = weight of flight controls lb or kg

W_g = design gross weight lb or kg

C = rotor blade chord ft or m

R = rotor radius ft or m

W_B = rotor blade weight per rotor lb or kg

a = adjusting factor for airship, fly-by-wire, etc.

k_{CC} = constant for cockpit controls (from ZPG - 2, ZPG - 3W) = 55 (English System), 34.5 (International System), a = 0.9 (Fly-By-Wire)
Cyclic and collective and airship control sticks and linkages, pedals, cables and rods (Fig. 5-65)

k_{RC} = constant for rotor rotating controls = 18
a = 1.0

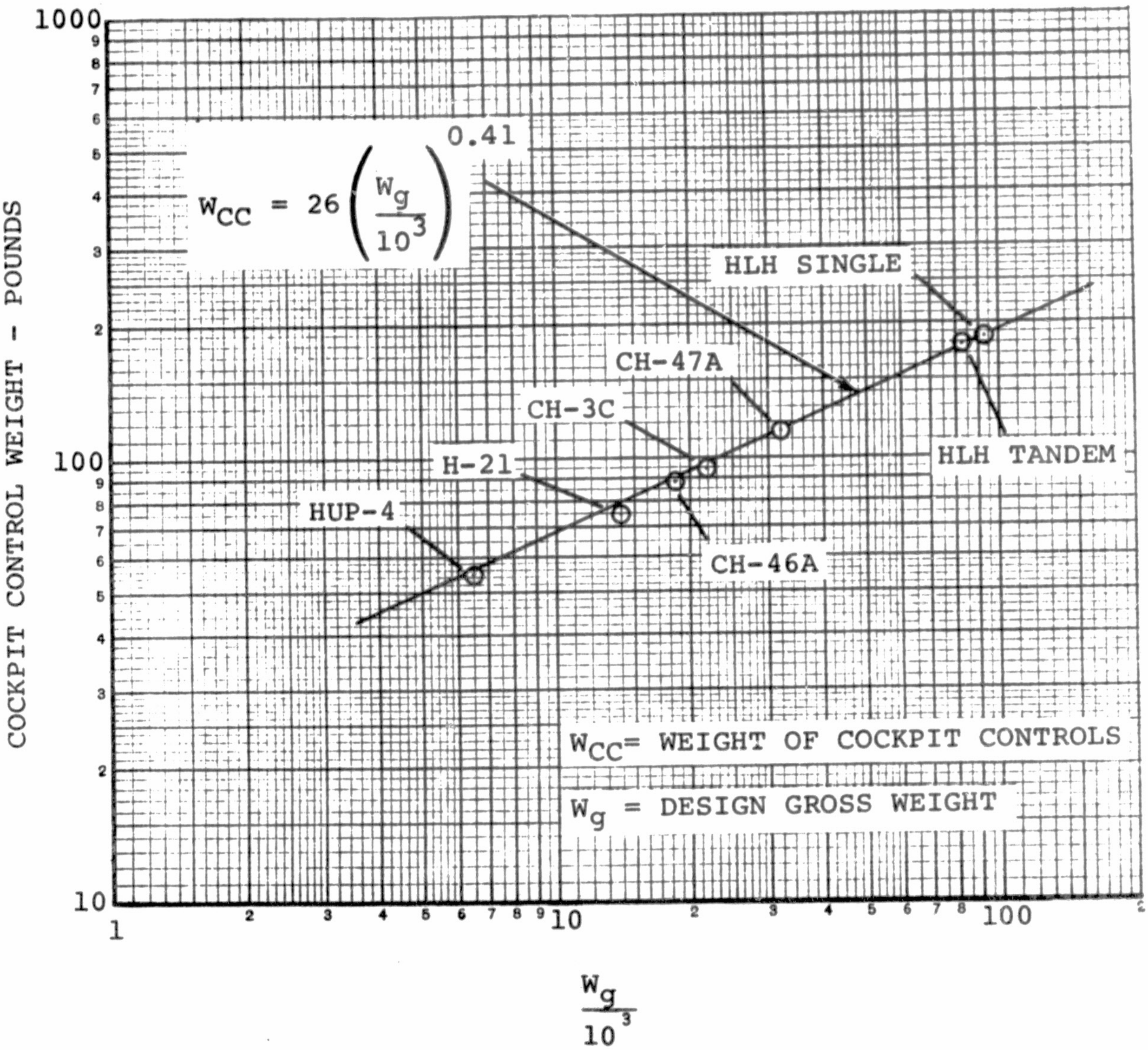
All components from and including the power actuators up through the pitch links. Major items included are the actuators, swashplate, and pitch links (Figure 5-66)

k_{SC} = constant for main rotor systems and hydraulics = 42 (English System), 37 (International System). a = 0.9 (Fly-By-Wire)
All components between the cockpit controls and the rotor controls including actuators, artificial feel system, mechanical programmer, bellcranks, rods, idlers, etc. (Figure 5-67)

Main hydraulic systems including pumps, reservoirs, accumulators, filters, valves, lines, fluid, and supports (Figure 5-67)

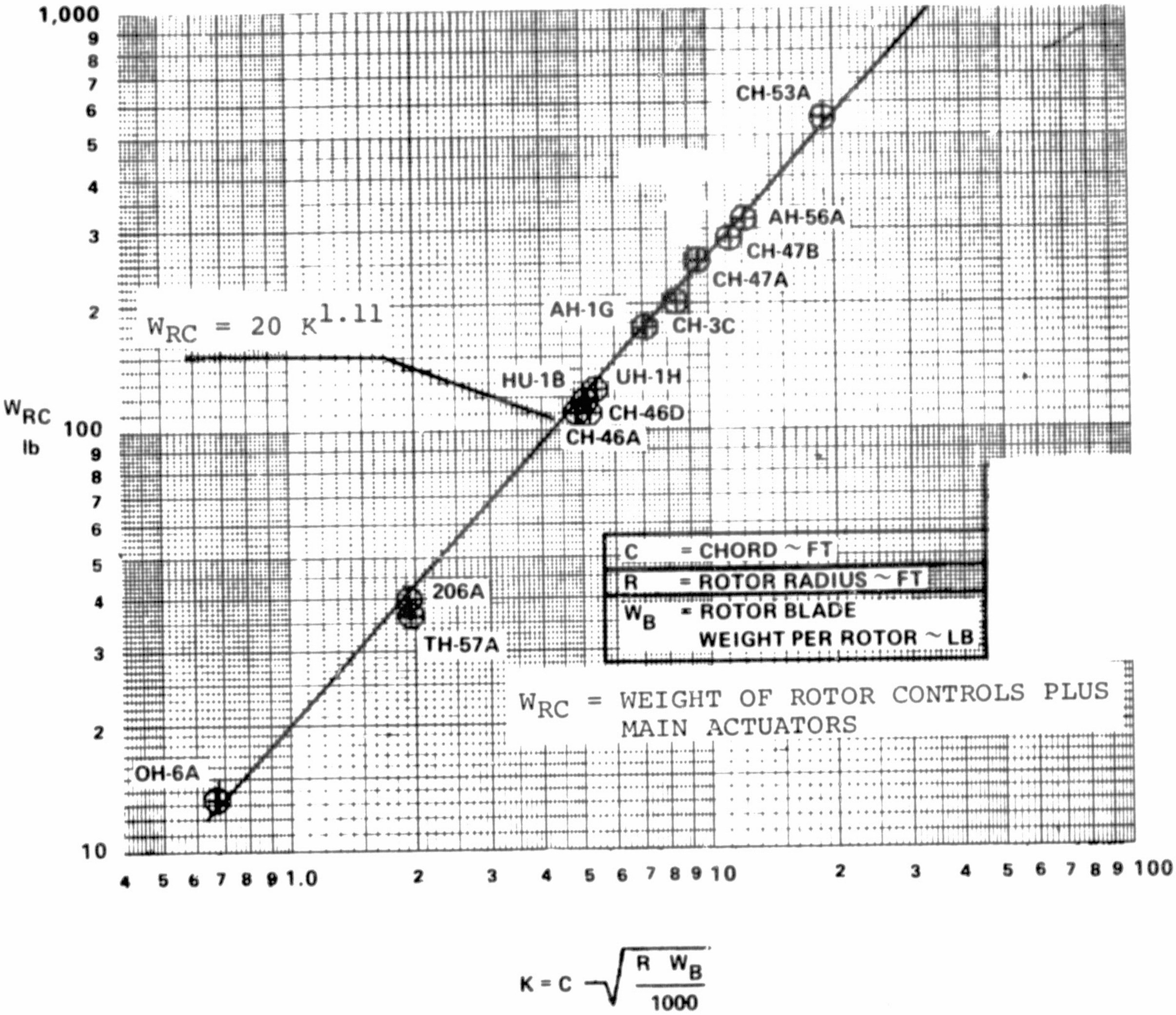
k_{FW} = constant for conventional fixed-wing controls = 0.005 a = 0.9 (fly-by-wire)

All components, actuators, and supports associated with moving the control surfaces



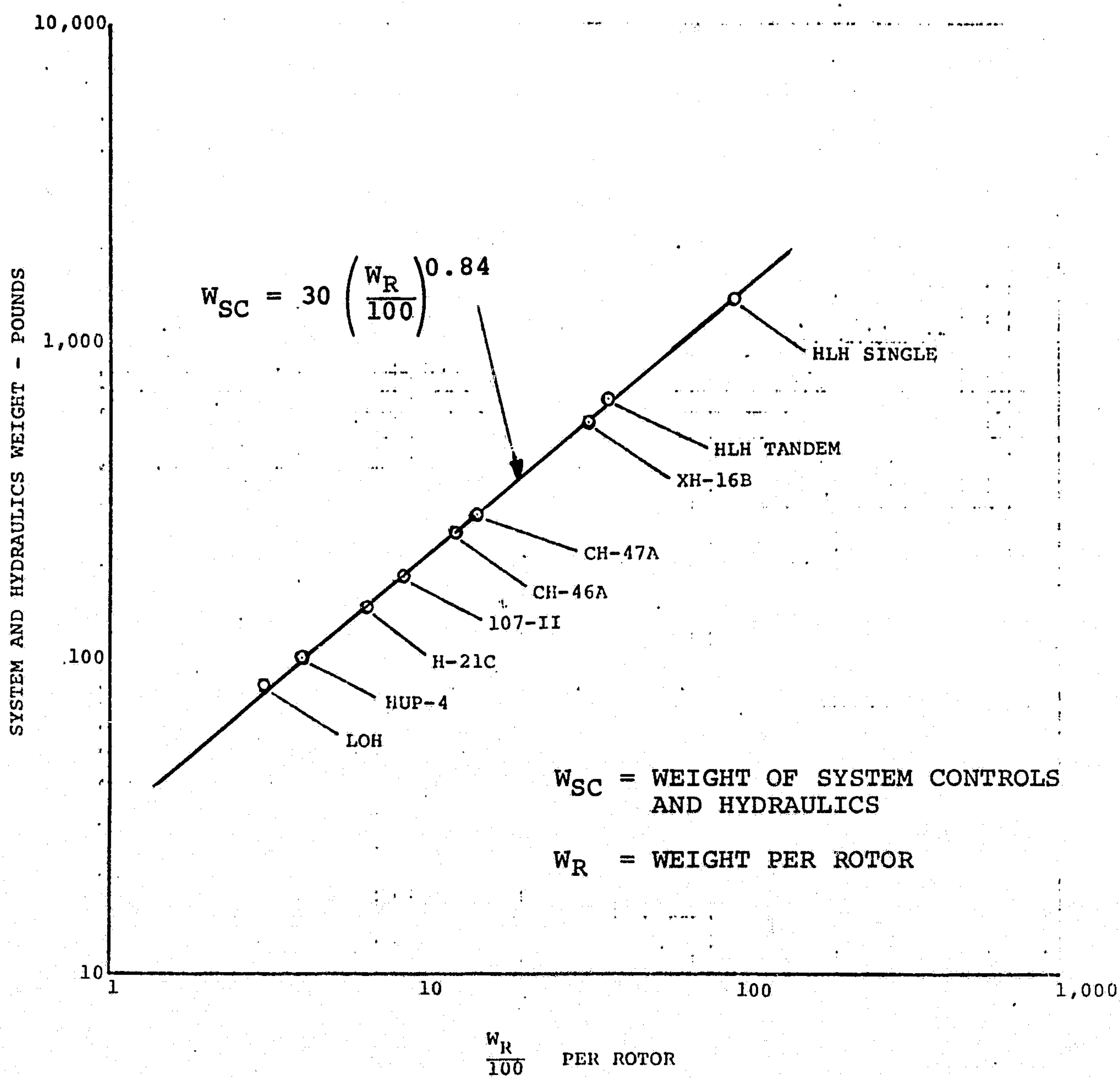
CONVERSION FACTOR: 1 lb = 0.454 kg

Figure 5–65. Cockpit Controls Weight Trend



CONVERSION FACTOR: 1 lb = 0.454 kg

Figure 5–66. Rotor Controls Weight Trend



CONVERSION FACTOR: 1 lb = 0.454 kg

Figure 5–67. Rotor System and Hydraulics Weight Trend

k_{TM} = constant for tilting mechanism - 0.29
a = 0.9 (fly-by-wire)

k_{SAS} = constant for an autopilot system = 200. pounds

k_{RCA} = constant for auxiliary rotor controls

Similar to k_{RC} - provides rotor control weights for propellers

k_{SCA} = constant for auxiliary rotor system controls

Similar to k_{SC} - provides rotor system control weights for propellers.

k_{BAL} = constant ballast and ballast system

Rigid

Ballast	=	$0.03\ W_g$
System	=	$0.016W_g$
		$0.046W_g$

K_{BAL} = 0.046 at 75% to 100% buoyancy

K_{BAL} = 0 at less than 75% buoyancy

Non-Rigid

	ZPG-2	ZPG-3W
Ballast	-	-
System	538	750
Total	538	750
Gross Wt.	60,800	82,905
	$0.008\ W_g$	$0.009\ W_g$

Use K_{BAL} = $0.009\ W_g$

K_{AS} = constant for airship controls based on ZPG-2 and APG-3W = 0.010, a = 0.9 (fly-by-wire)

k_{Misc} = estimated weight input in pounds of killograms for any items not covered above

16. Fixed Equipment

The weight of the fixed equipment is included in the weight empty and consists of the following groups: auxiliary power-plant, instruments, hydraulics and pneumatics, electrical, avionics, armament, furnishings and equipment, air-conditioning, anti-icing and load and handling.

For this study the weight of the avionics and instruments have been determined. The furnishings are based on number of crew and passengers. The remainder are determined by percent of gross weight.

Avionics and Instruments and Navigation

Communications	178. Lb	80.7 kg
Engine Instruments	57.	25.9
Flight Instruments	50.	22.7
Navigation Equipment	183.	83.0
Misc	46.	20.9
Installation 36%	186.	84.4
Total	700. Lb	317.6 kg

Fixed Equipment	% Gross Weight
Auxiliary Power Plant	0.9
Hydraulics	0.5
Electrical	3.3
Misc Equipment	0.2
Emergency Equipment	0.4
Air Conditioning	1.6
Anti-Icing	0.1
Auxiliary Gear	
Winch, Etc.	0.7
Handling Lines	0.3

Furnishings — 80 lb/man (Crew and PAX)
36.3 kg/man

17. Food and Water

Food 2.5 lb/man/day 1.13 kg/man/day

Water

Drinking = 2.0 liters/man/day
Cooking = 0.5 liters/man/day
Sanitation = 4.5 liters/man/day

Total Water 7.0 liters/man/day

or

15 lb/man/day (Crew and PAX)
6.8 kg/man/day

5.4.2.7 Cruise Static Stability Criteria

Although stability considerations are not required for the current parametric studies, a limited amount of work is necessary to ensure that parametric aircraft are reasonable. Figure 5-68 shows some airship static stability trends. Tail arm times area is plotted as a function of airship volume. Conventional airship tail parameters have been placed on the figure and a line representing approximately neutral stability has been added. As can be discerned, all of the conventional airships plotted are unstable. An airship could be made completely stable by making the fins large enough. The primary reason for not doing this is to obtain improved maneuverability by using this instability. A turn can be executed more easily because the instability allows the nose to swing into the turn. This instability, however, requires constant crew attention to maintain direction.

For preliminary design purposes, the following recommendations are made relative to empennage sizing:

a) Advanced LTA craft with large lifting surfaces should be neutrally stable and adhere closely to conventional airplane practice. The neutral static stability trend line is, therefore, recommended. This will also tend to make the airship less gust sensitive.

b) For conventional airships or airships with low fineness ratio hulls, the conventional airship trend line is recommended.

It should be emphasized that these recommendations are very preliminary and that stability requirements for airships should be studied in detail.

5.4.3 Parametric Results

5.4.3.1 General

This section contains the results of the LTA vehicle parametric study, which was performed using the

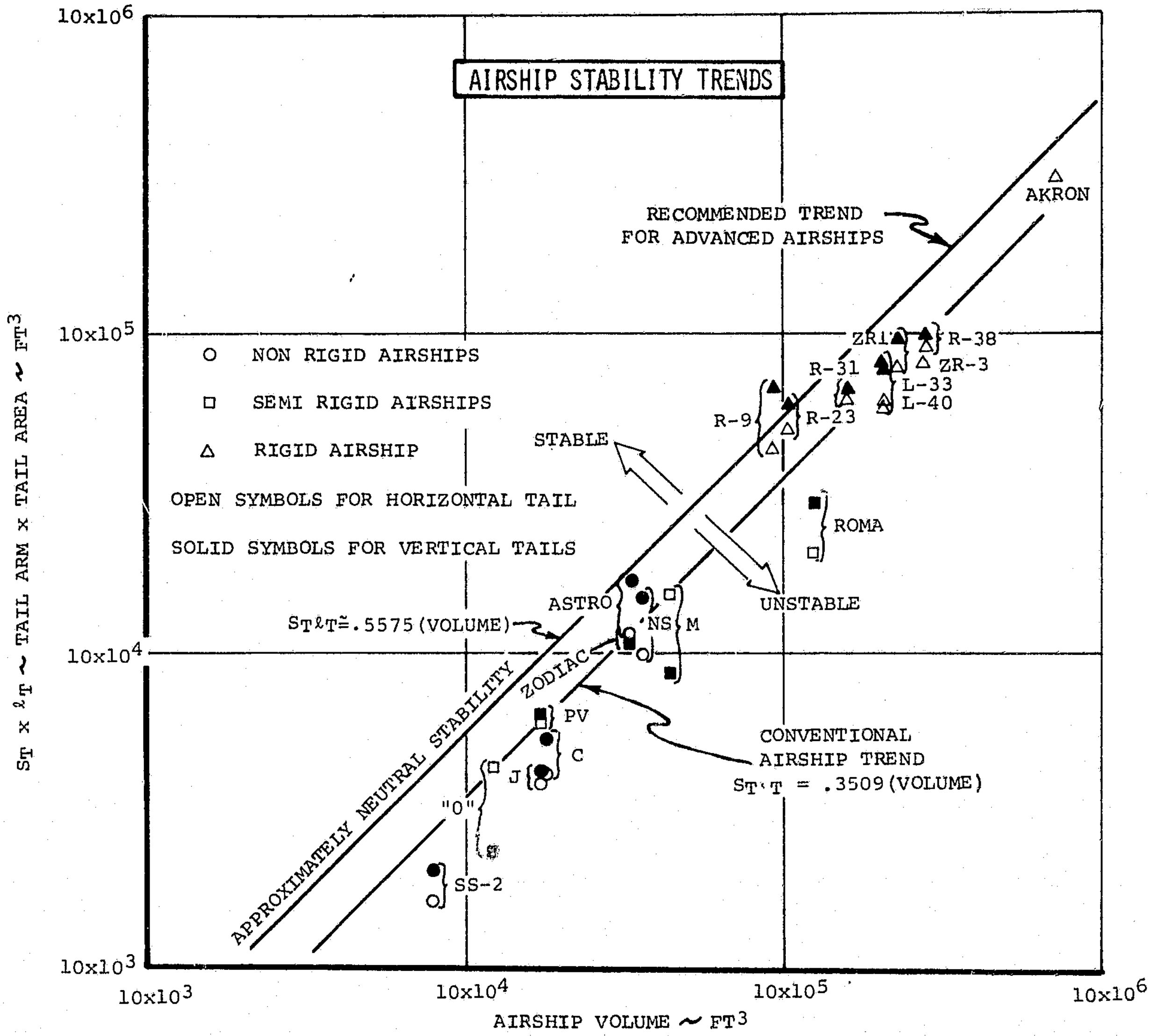


Figure 5–68. Airship Stability Trends

CASCOMP computer program. Six airship configurations were evaluated at two buoyancy ratios (.35 and .75), three design cruise speeds (50, 100 and 200 kt), (25.7, 51.4 and 102.9 m/s) and three design missions for gross lifts ranging from 60,000 to 6,000,000 lb (27,216 to 2,721,600 kg). From the data thus developed, the variation of gross lift with design cruise speed at a given payload was determined for each configuration. It should be noted that the definition of buoyancy ratio is buoyant lift divided by static weight. A low buoyancy ratio means that a large amount of aerodynamic lift is required to sustain flight. A buoyancy ratio of 1.0 requires no aerodynamic lift to sustain flight. Further, the hull size increases with increasing buoyancy ratio. In order to examine the relative merits of these various configurations, specific productivity (payload (P) x speed (V): empty weight (E) has been determined as a function of design cruise speed. In a study of this sort, specific productivity is a relatively simple substitute for direct operating cost (DOC) which allows comparison between configurations without having to establish development and acquisition costs, utilization, maintenance, and crew costs which, at this stage of airship development are extremely nebulous as well as controversial.

Specific configuration performance will now be examined in more depth for the following configurations:

- Conventional Nonrigid Airship
- Confentional RIGID Airship
- Dynairship
- Megalifter
- Helipsoid
- Helistat

5.4.3.2 Conventional Rigid and Nonrigid Airships Parametric Results

Figure 5-69 depicts gross lift as a function of design cruise speed at design payloads of 100,000 (45,360) and 200,000 lb (90,720 kg) for the short range (300 N.M.) (556 km) mission.

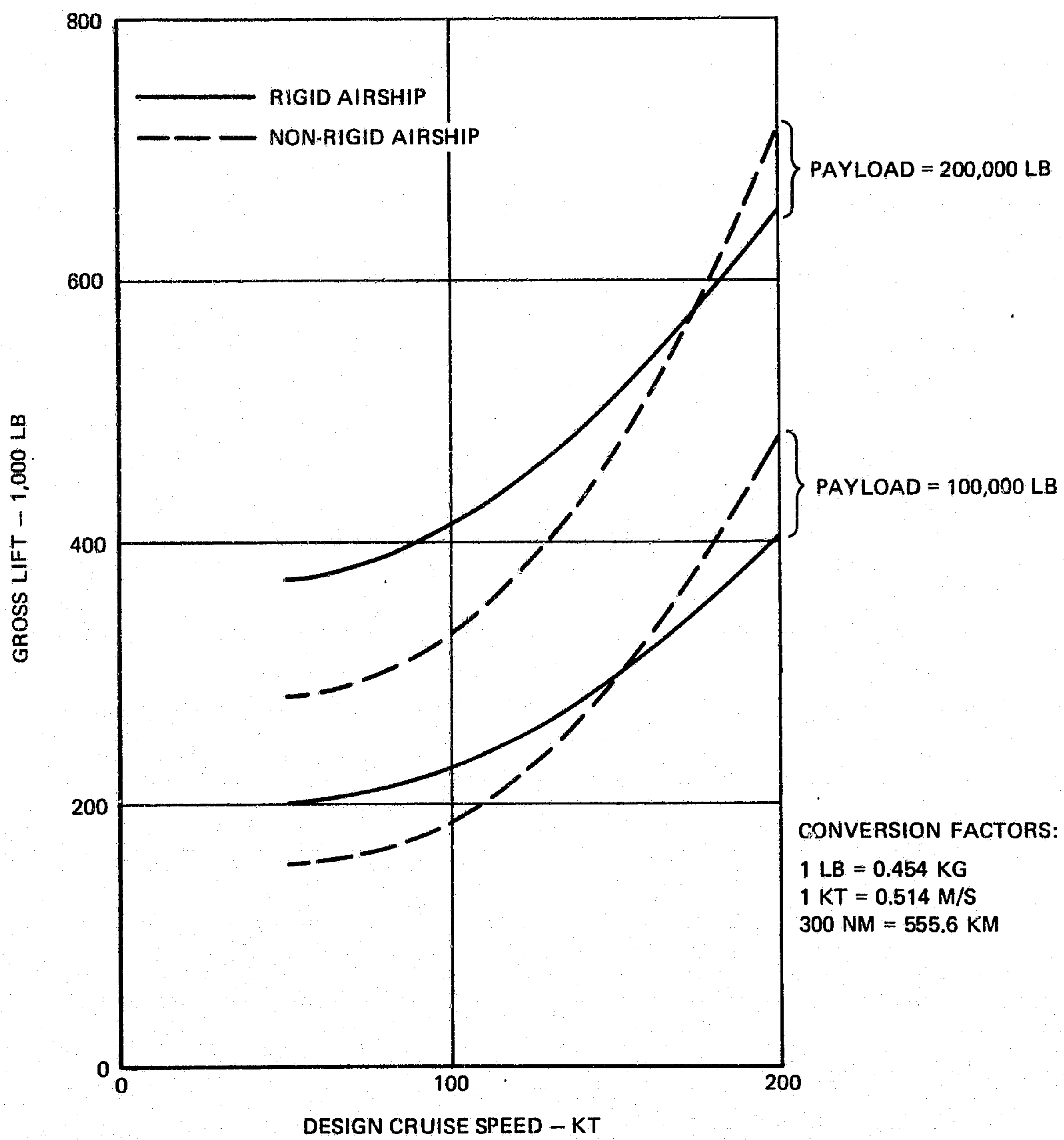
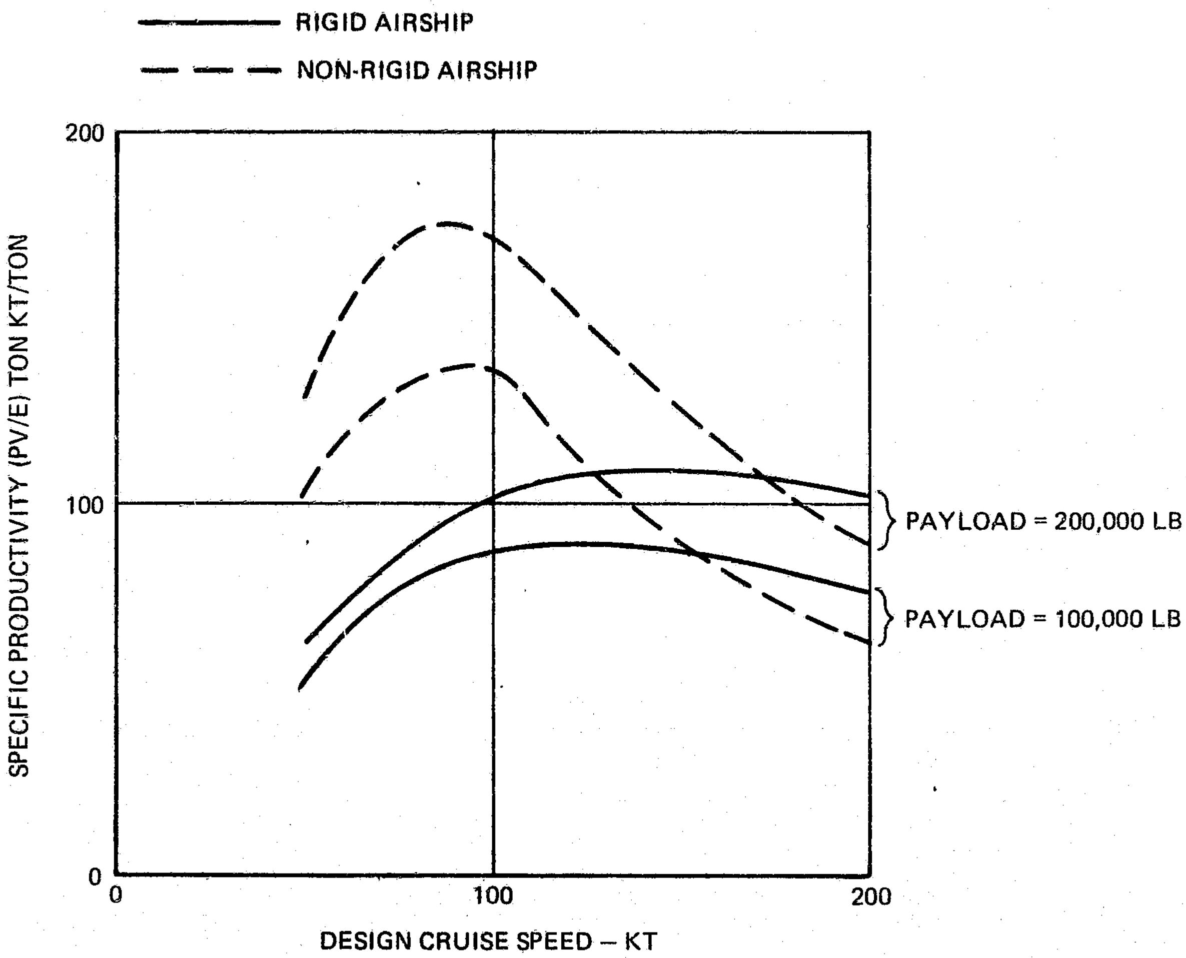


Figure 5–69. Conventional Airship Trend Study, 300 N.M. Short Range Mission – Gross Lift Requirements

ume slightly greater than a corresponding rigid airship at the same gross lift, due to a lower ratio of gas cell volume/hull volume. (.905 vs .925 for the rigid airship). This is due to an extra volume requirement for the ballonet, resulting in a lower ratio - this, in spite of the fact that the nonrigid airship doesn't have to satisfy the 6-inch internal structure/gas cell clearance and 2.5% miscellaneous equipment volume requirement of the rigid airship. Also, note that (for a given payload) at the higher design cruise speeds, the nonrigid airships require a larger gross lift than the corresponding rigid airships. This reflects the increasing weight penalty (increase in structural empty weight) resulting from the requirement of the nonrigid airship's skin to contain the lifting gas and at the same time maintain a smooth aerodynamic shape at increasing flight dynamic pressures. In fact, speed limitations on the modern nonrigid airship, due to the high internal pressurization required, appear to be of the order of 100 kt (51.4 m/s). Also, based on maximum fabric strength capabilities, the nonrigid size range should be limited to a diameter of 160-160 ft (48.8 - 54.9 m) resulting in a volume limitation slightly more than 10,000,000 ft^3 (283,200 m^3).

The specific productivity plot (Figure 5-70) also reflects this condition (note the rigid-nonrigid crossover) at the higher design cruise speeds. Figure 5-71 shows the payload capabilities of the rigid and nonrigid airships as a function of gross lift for the various design cruise speeds. Figures 5-72 and 5-73 illustrate, respectively, the mission performance and configuration definitions for both types of airships.

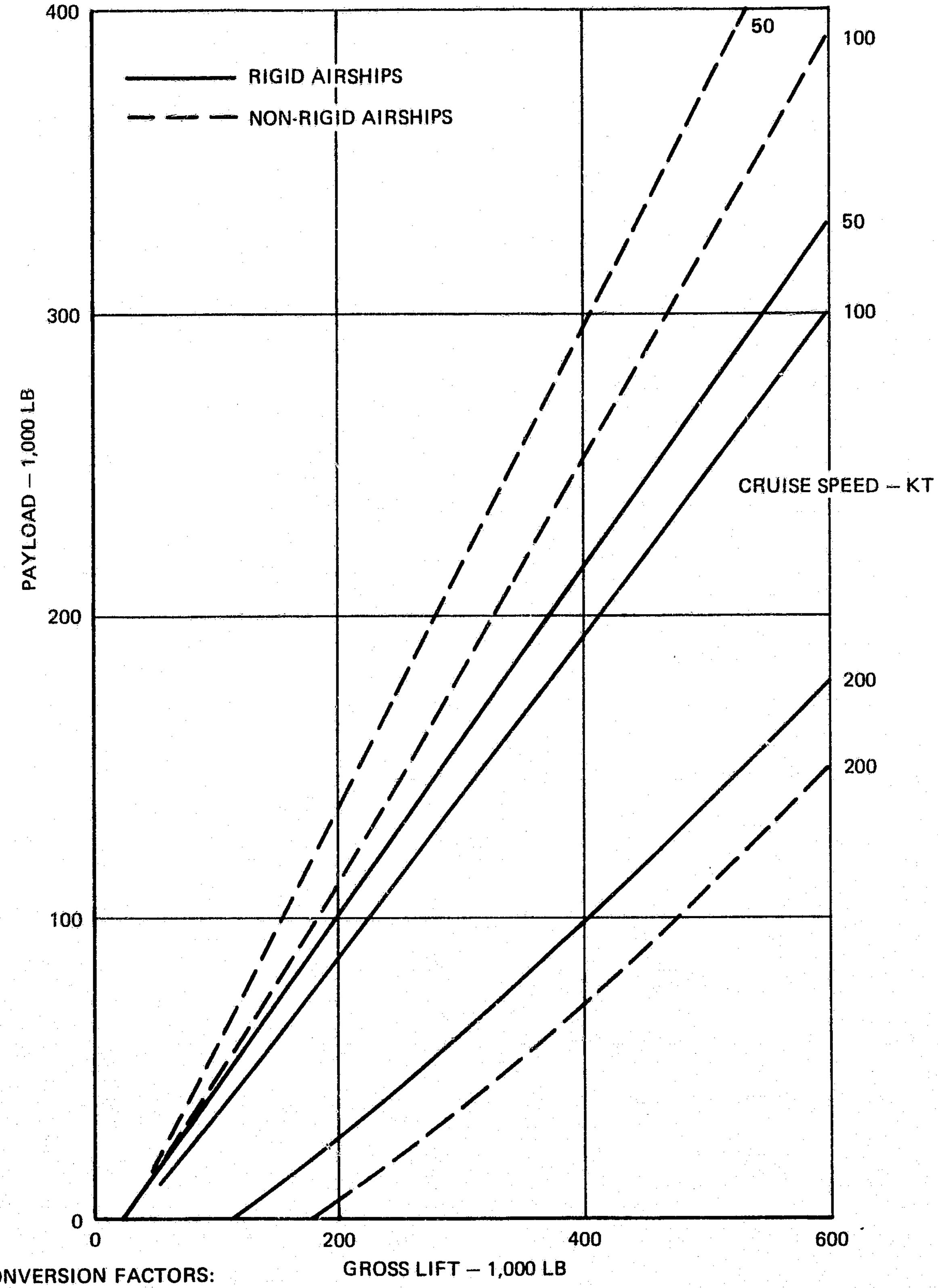
Figures 5-74, 5-75, 5-76, 5-77, and 5-78 depict, respectively, the gross lift requirement, specific productivity, payload capability, mission performance, and configuration definition at a payload of 200,000 lb (90,720 kg) for the transcontinental mission (2000 N.M.) (3,704 km). Note that these data no longer show any crossovers between the nonrigid and rigid configurations at high design speeds. The nonrigid airship envelope



CONVERSION FACTORS;

1 LB = 0.454 KG
1 TONKT/TCN = 0.514 M.TON x M/S/M.TON
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

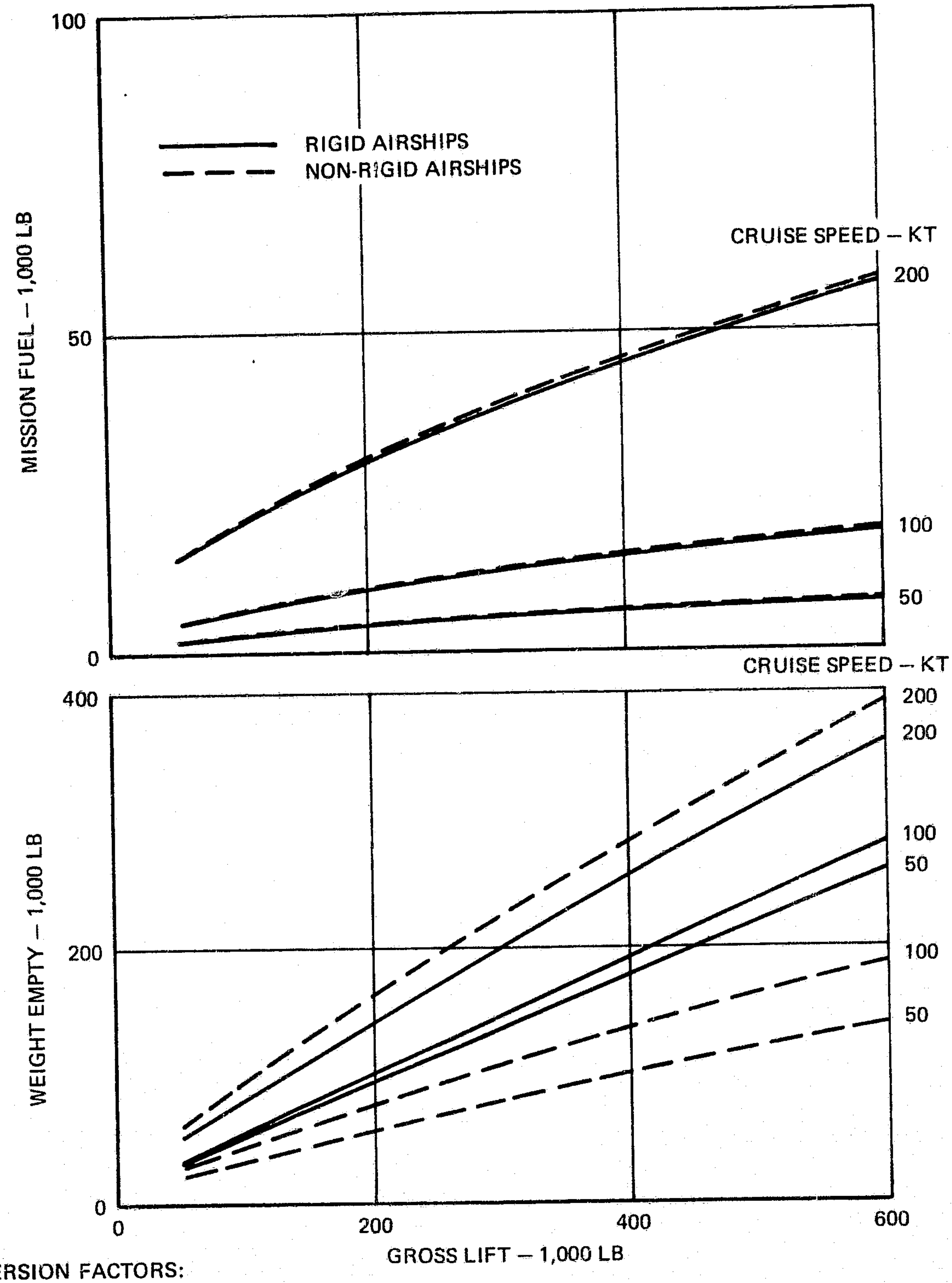
Figure 5–70. Conventional Airship Trend Study, 300 N.M. Short Range Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG 1 KT = 0.514 M/S 300 N.M. = 555.6 KM

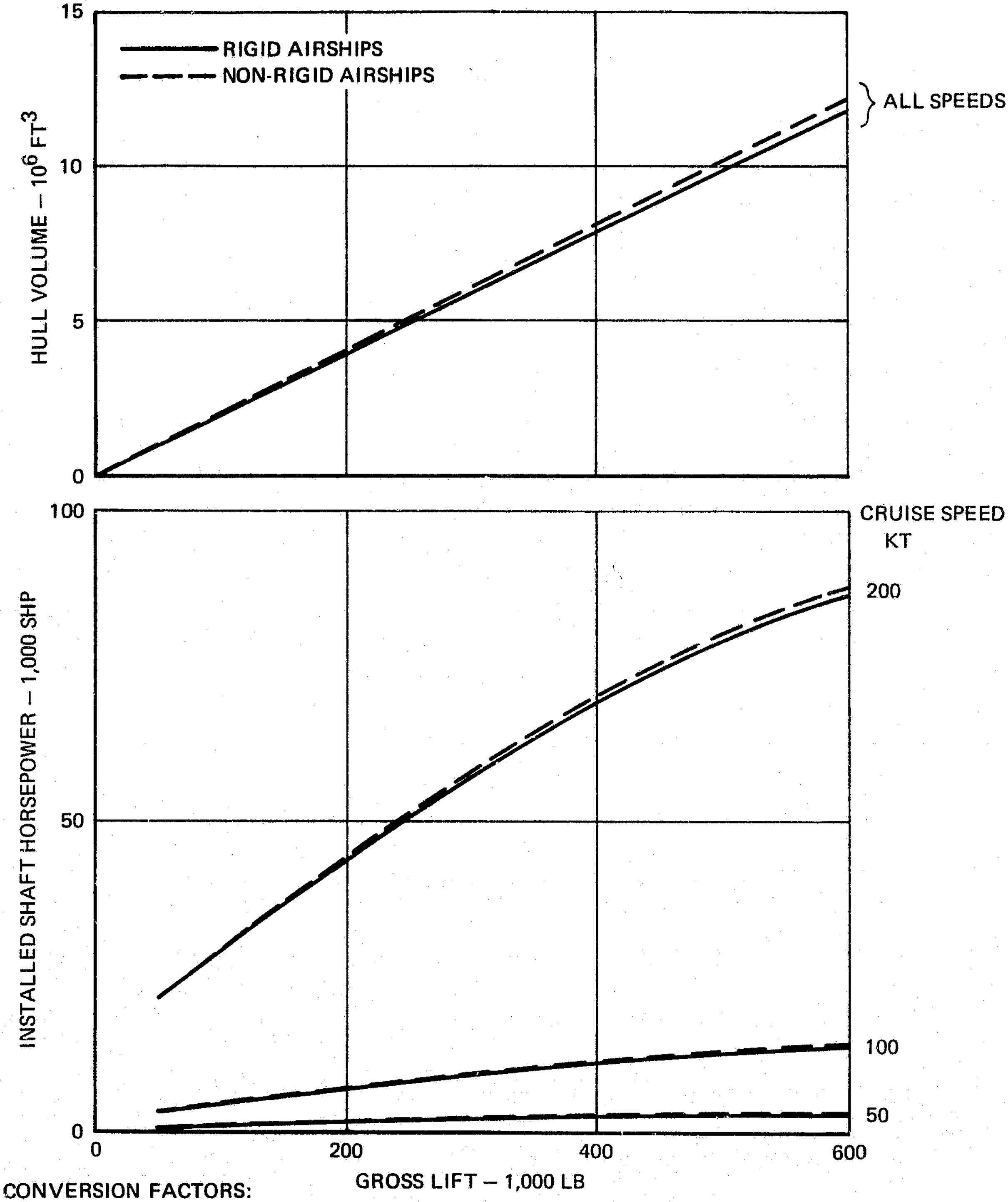
Figure 5–71. Conventional Airship Trend Study, 300 N.M. Short Range Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

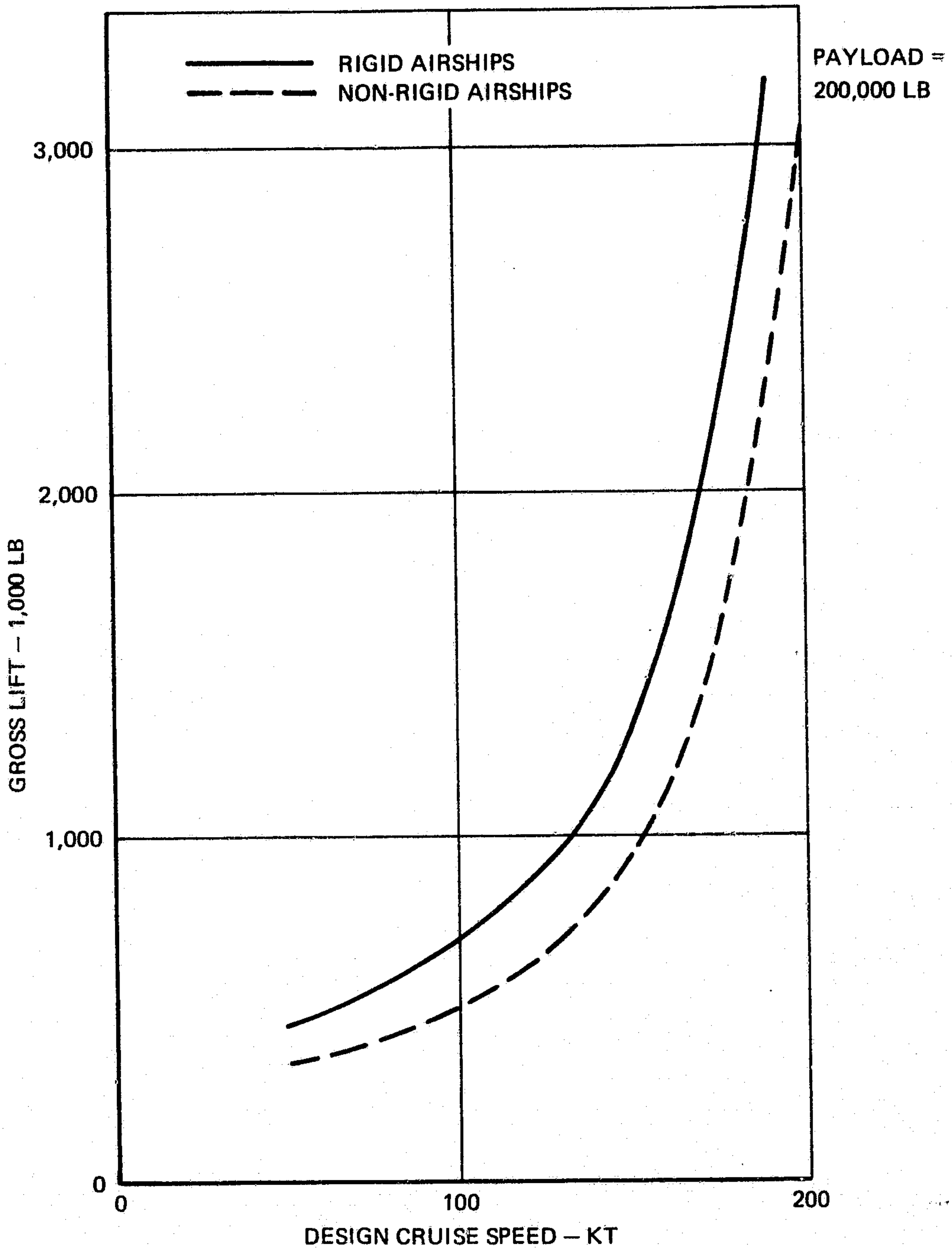
Figure 5–72. Conventional Airship Trend Study, 300 N.M. Short Range Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
300 N.M. = 555.6 KM

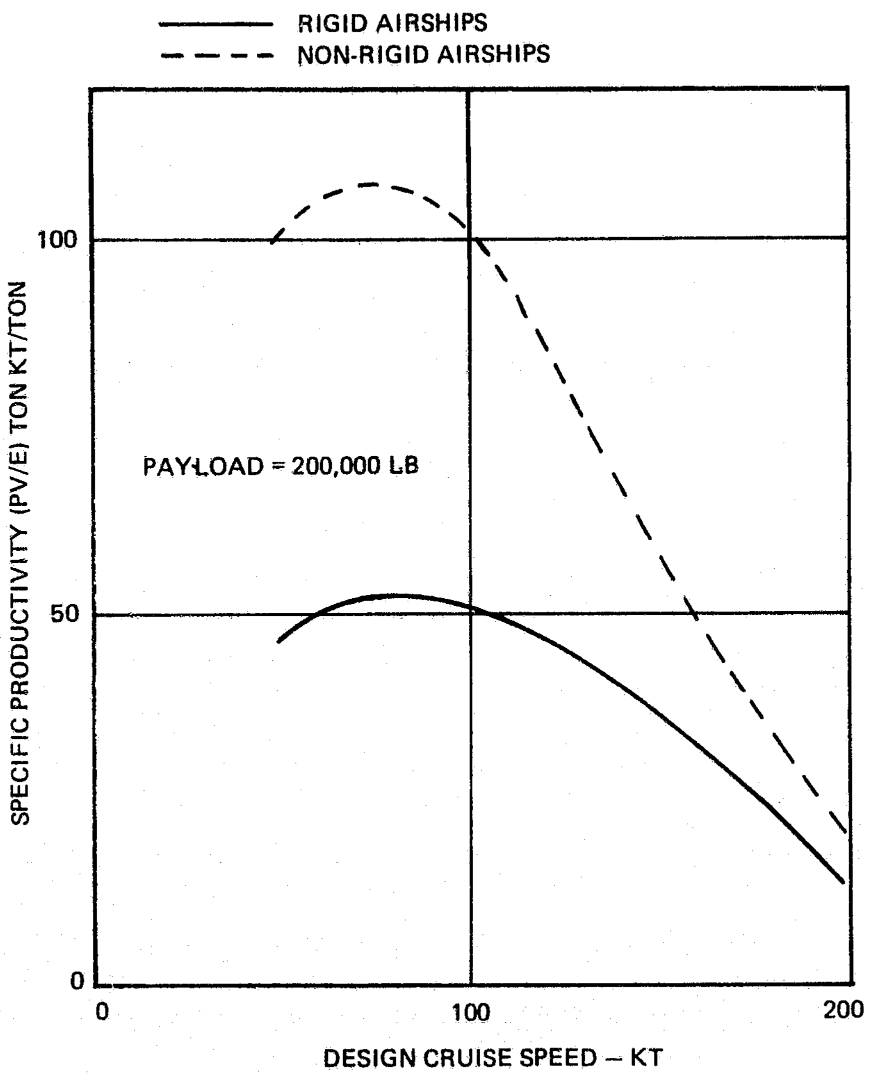
Figure 5–73. Conventional Airship Trend Study, 300 N.M. Short Range Mission – Configuration Definition



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

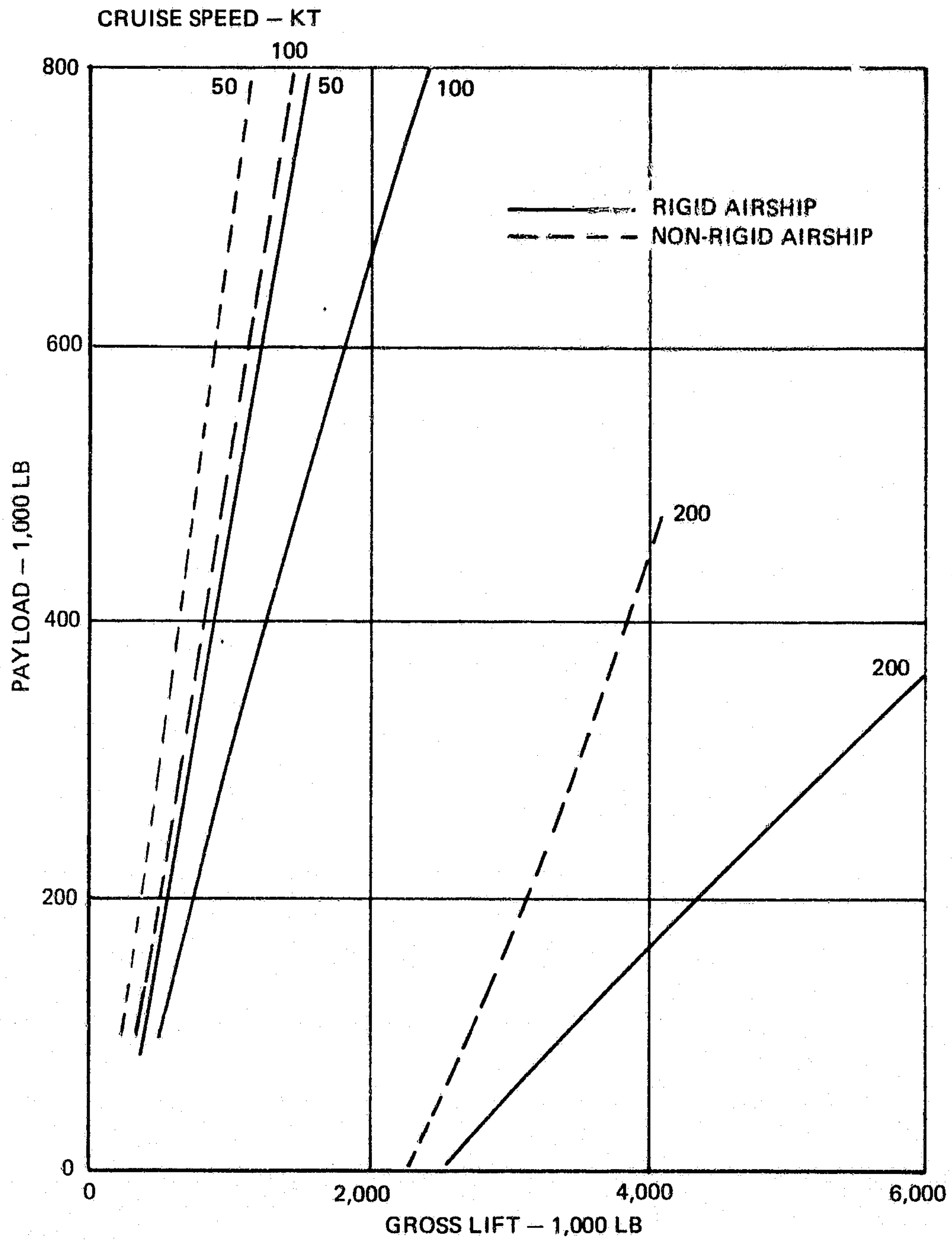
Figure 5–74. Conventional Airship Trend Study, 2,000 N.M. Transcontinental Mission – Gross Lift Requirements



CONVERSION FACTORS:

1 LB = 0.454 KG
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

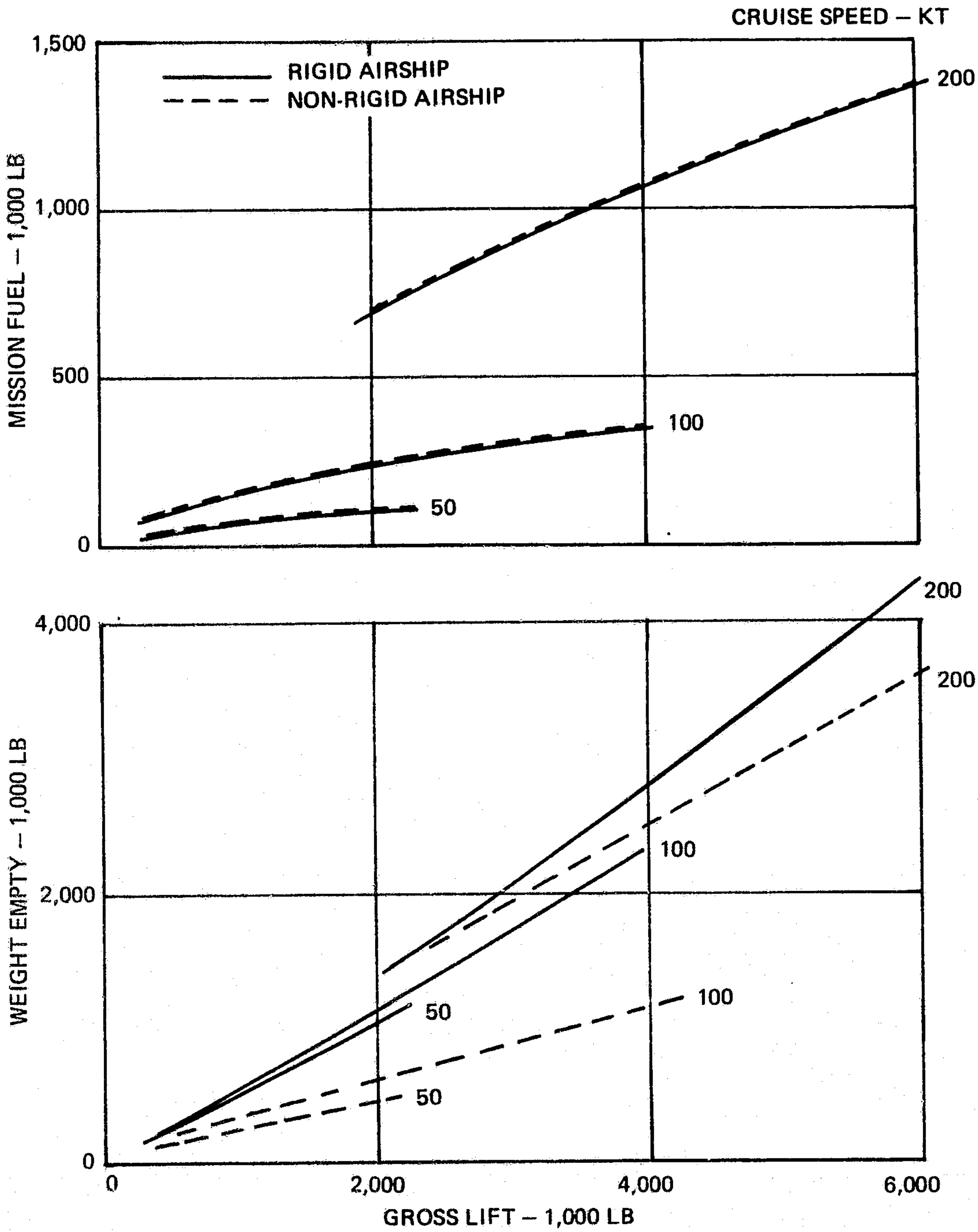
Figure 5–75. Conventional Airship Trend Study, 2,000 N.M. Transcontinental Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

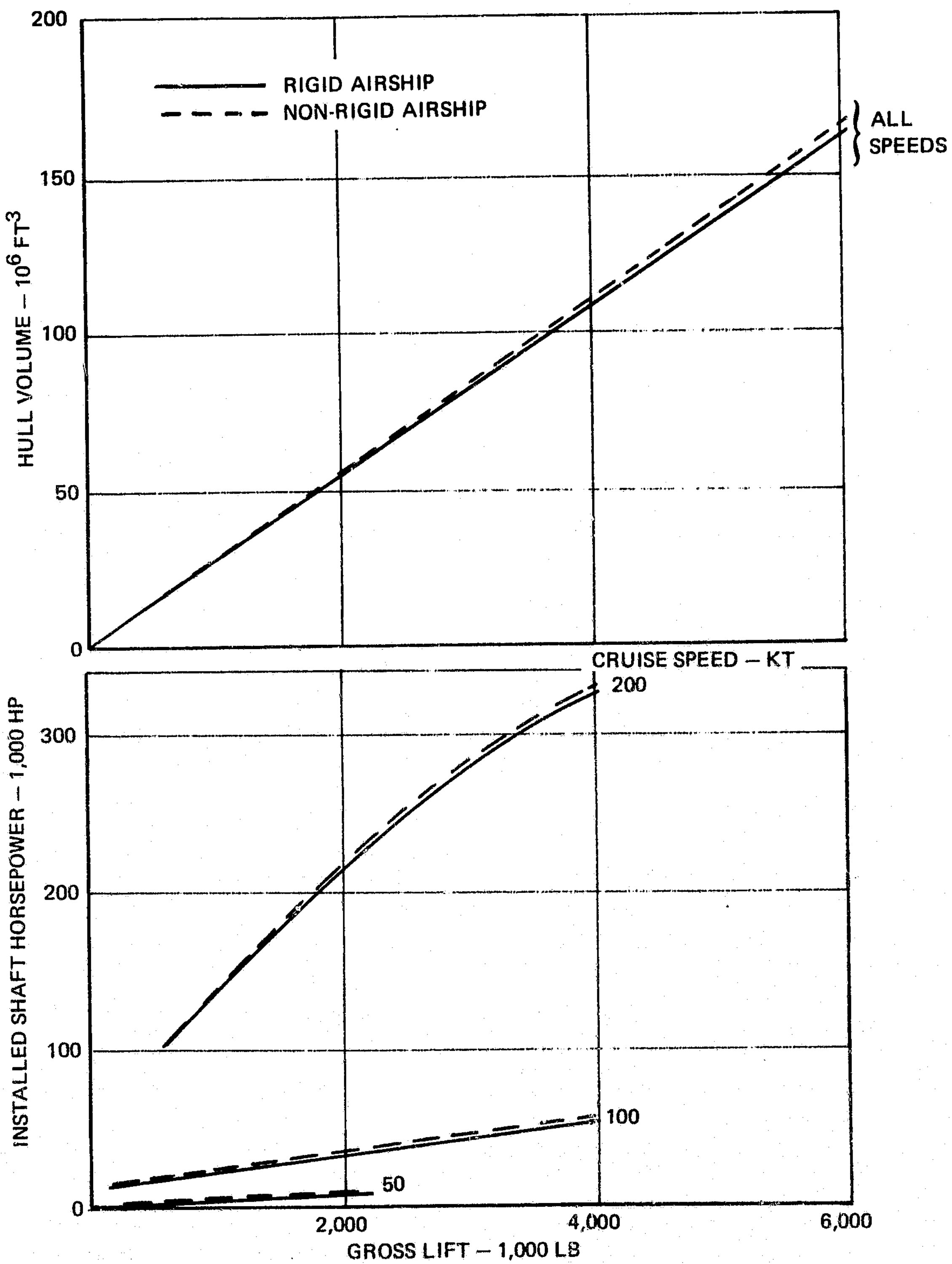
Figure 5–76. Conventional Airship Trend Study, 2,000 N.M. Transcontinental Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

Figure 5–77. Conventional Airship Trend Study, 2,000 N.M. Transcontinental Mission – Mission Performance



CONVERSION FACTORS: 1 LB = 0.454 KG $1\ FT^3 = 0.0283\ M^3$
1 KT = 0.514 M/S 2,000 N.M. = 3,704 KM

Figure 5–78. Conventional Airship Trend Study, 2,000 N.M. Transcontinental Mission - Configuration Definition

structural penalty still exists at the higher speeds, but it is dwarfed in magnitude by a combination of increased mission fuel weight and fuel system weight resulting from the longer mission.

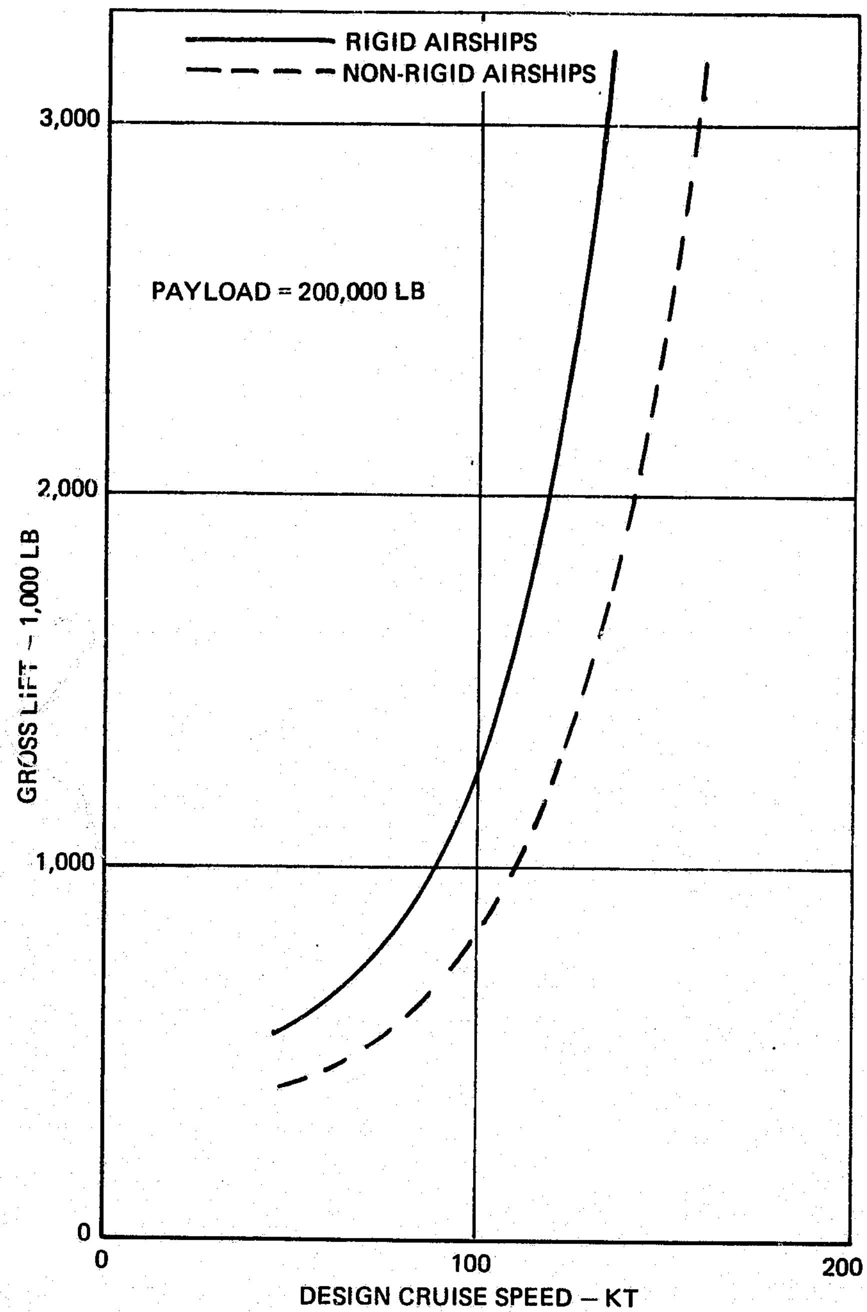
Figures 5-79, 5-80 , 5-81, 5-82, and 5-83 depict, respectively, the data noted previously at a payload of 200,000 lb. for the intercontinental mission (5000 N.M.).

5.4.3.3 Dynairship Parametric Results

The parametric study results of the Dynairship lighter-than-air configuration are documented in this section. The Dynairship configuration, described in detail in Section 5.3.1.3, is a partially buoyant concept with a low aspect ratio, highly swept delta shape and a thickness of about 22%. This fundamental shape is not geometrically efficient in that a given hull volume has about 13% more surface area than other configurations studied. This difference, which can be seen by comparing the geometry plots of Section 5.3, means that the Dynairship will have at least 13% more drag than any other configuration. In addition, its low aspect ratio results in high induced drag.

Figure 5-84 shows gross lift as a function of design cruise speed for design payloads of 100,000 and 200,000 lb., for the short range (300 N.M.) mission. Buoyancy ratios of 0.35 and 0.75 are shown. It should be noted that the definition of buoyancy ratio is buoyant lift divided by static weight. A low buoyancy ratio means that a large amount of aerodynamic lift is required to sustain flight. A buoyancy ratio of 1.0 requires no aerodynamic lift to sustain flight. The hull envelope size increases with buoyancy ratio. These data show that, for a given payload, the buoyancy ratio of 0.35 results in a smaller, lighter configuration. The minimum gross lift configuration occurs at a speed of approximately 120 kts. The characteristic shape of the curves at a buoyancy ratio of 0.35 is attributed to the fact that at low speeds, the low aspect ratio Dynairship has high induced drag. This means that the power and fuel required to perform the mission is high and a relatively

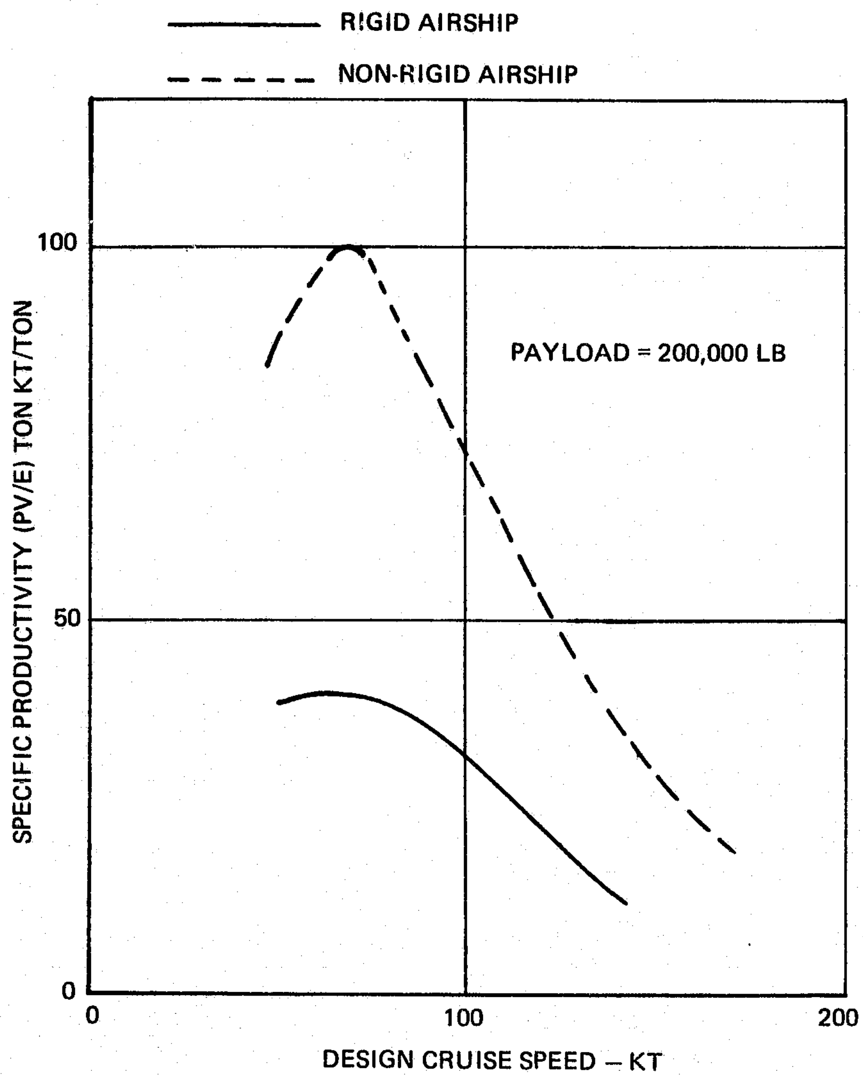
C-4



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

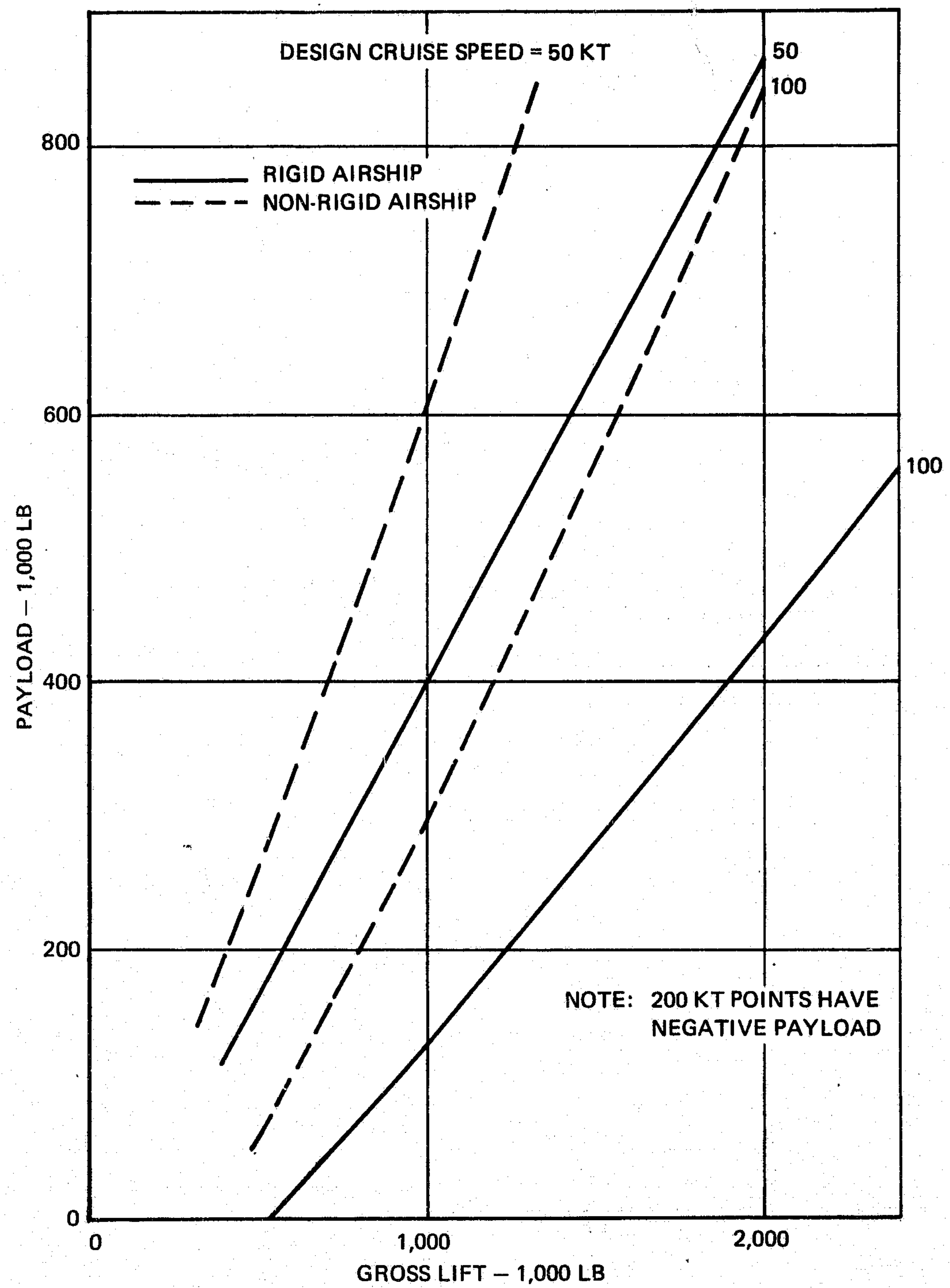
Figure 5–79. Conventional Airship Trend Study, 5,000 N.M. Intercontinental Mission – Gross Lift Requirements



CONVERSION FACTORS:

1 LB = 0.454 KG
1 TONKT/KT = 0.514 M.TON x M/S/M.TON
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

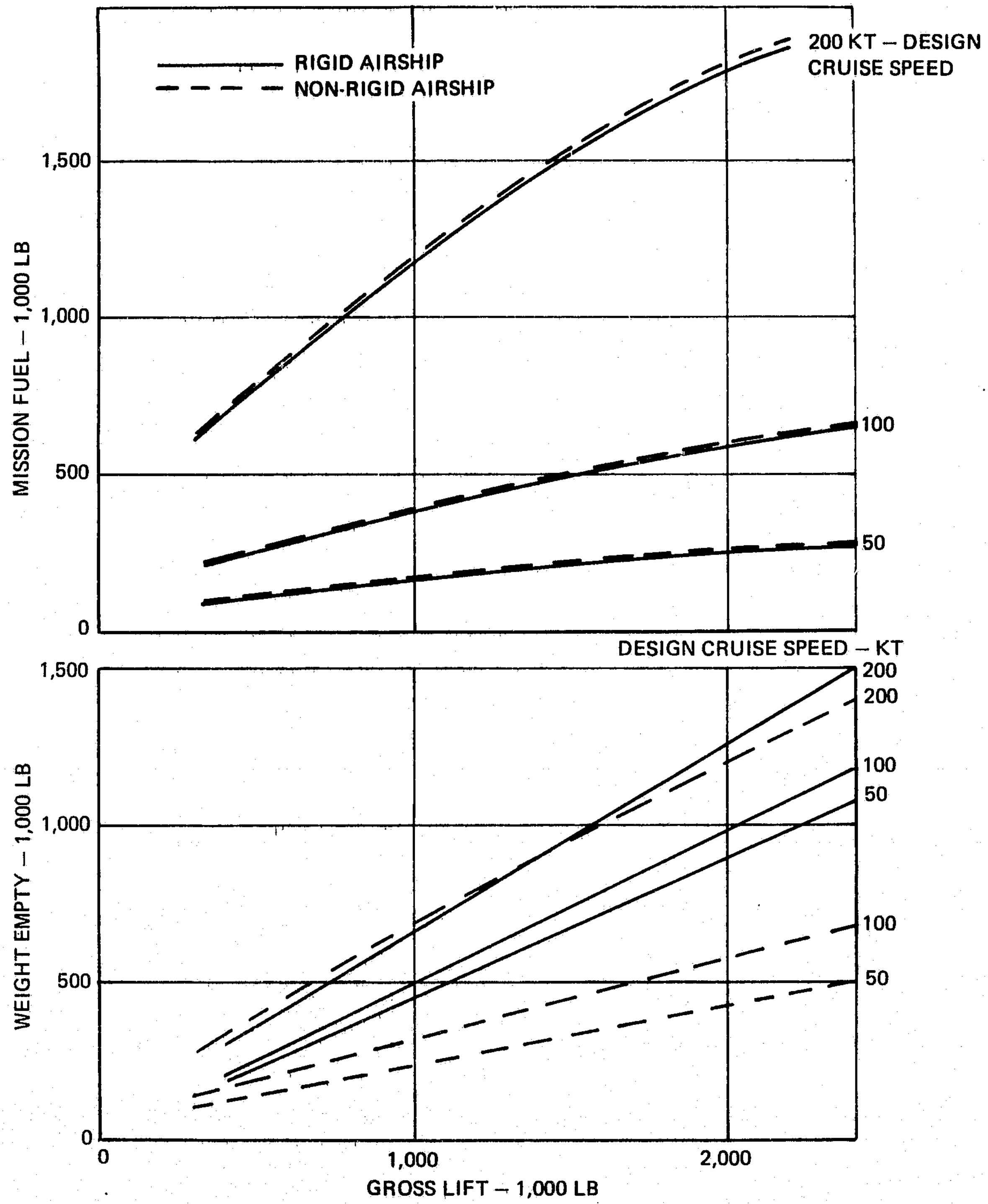
Figure 5–80. Conventional Airship Trend Study, 5,000 N.M. Intercontinental Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

Figure 5–81. Conventional Airship Trend Study, 5,000 N.M. Intercontinental Mission – Payload Capability



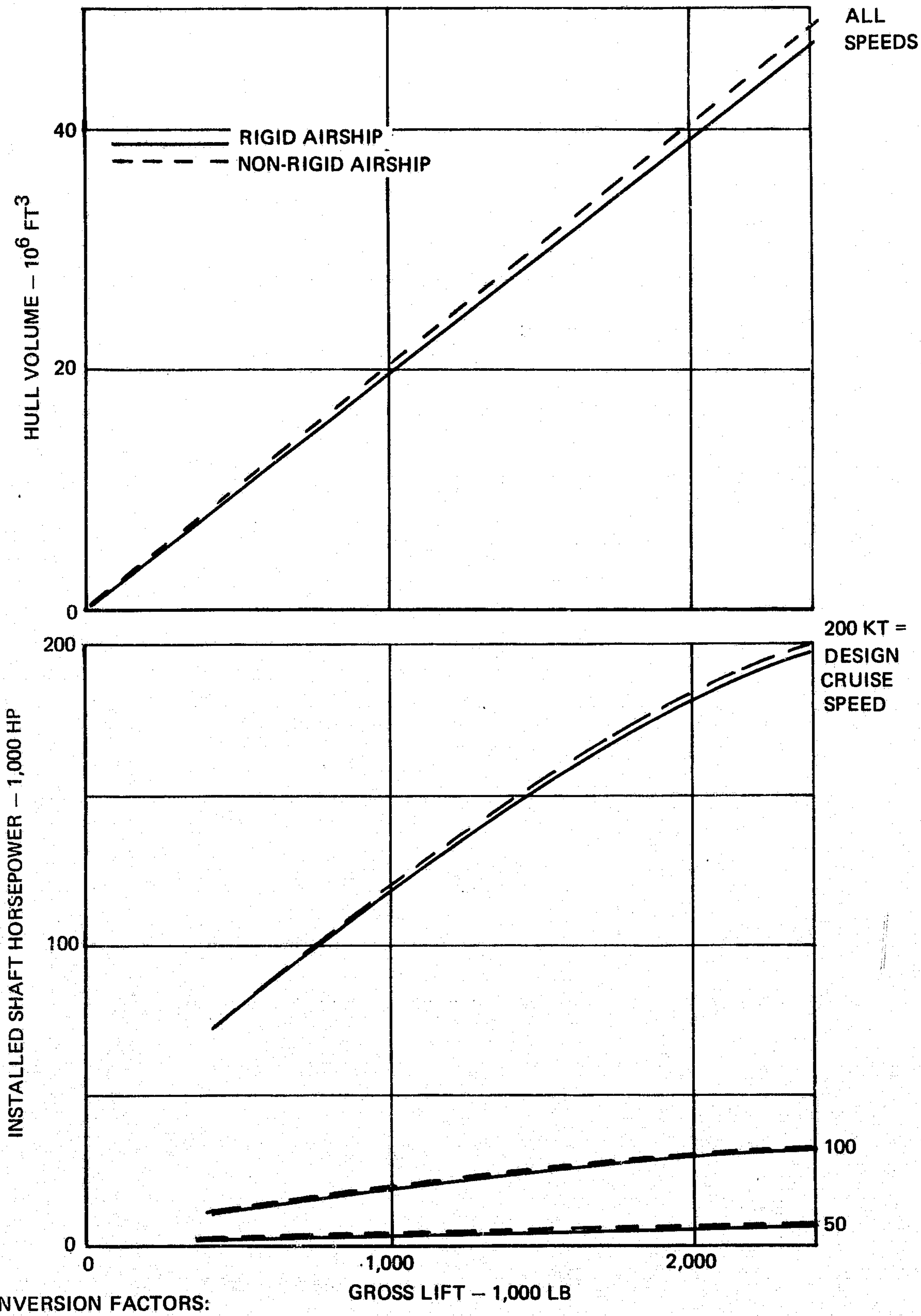
CONVERSION FACTORS:

1 LB = 0.454 KG

1 KT = 0.514 M/S

5,000 N.M. = 9,260 KM

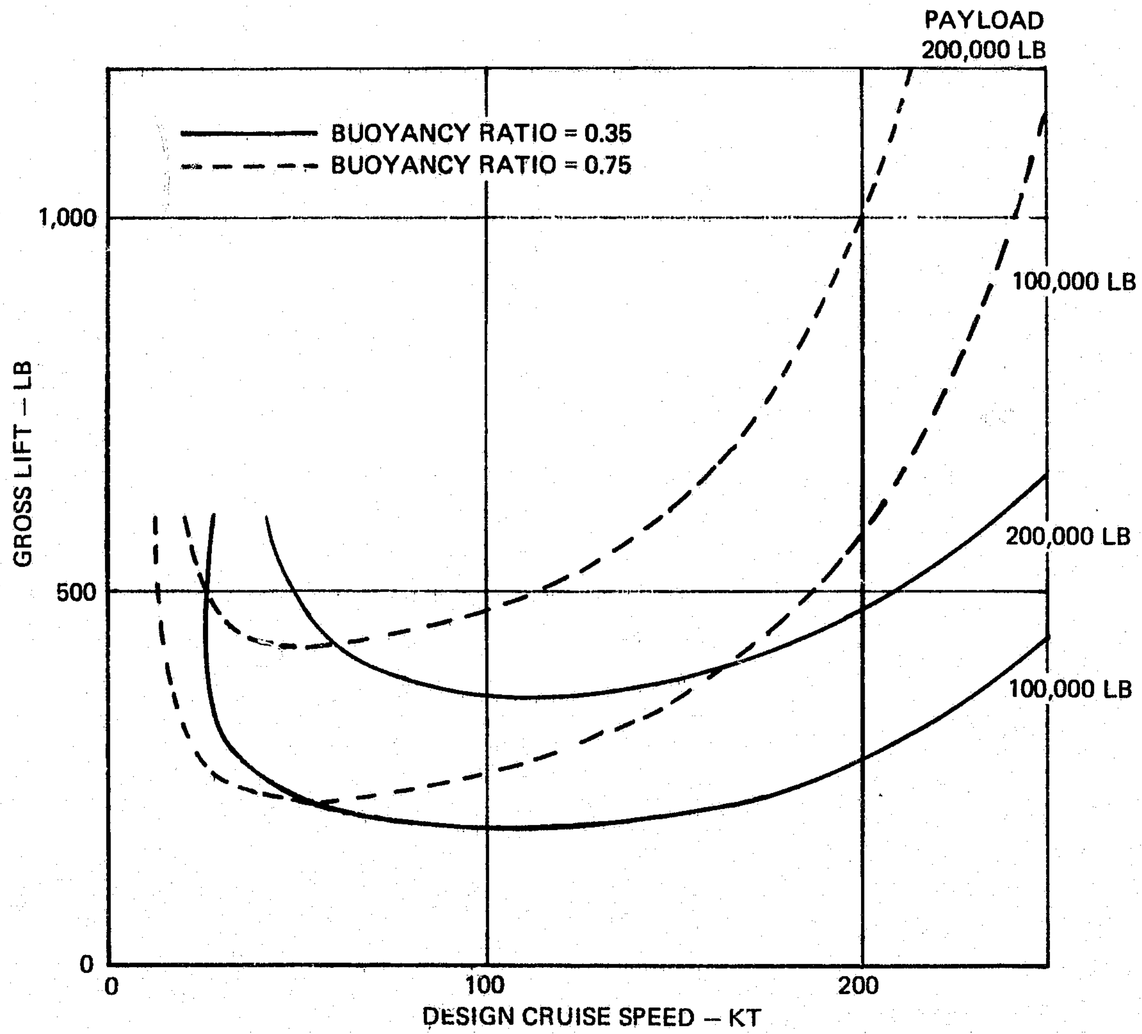
Figure 5–82. Conventional Airship Trend Study, 5,000 N.M. Intercontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG 1 KT = 0.514 M/S 1 FT^3 = 0.0283 M^3 5,000 N.M. = 9,260 KM

Figure 5–83. Conventional Airship Trend Study, 5,000 N.M. Intercontinental Mission — Configuration Definition



CONVERSION FACTORS:

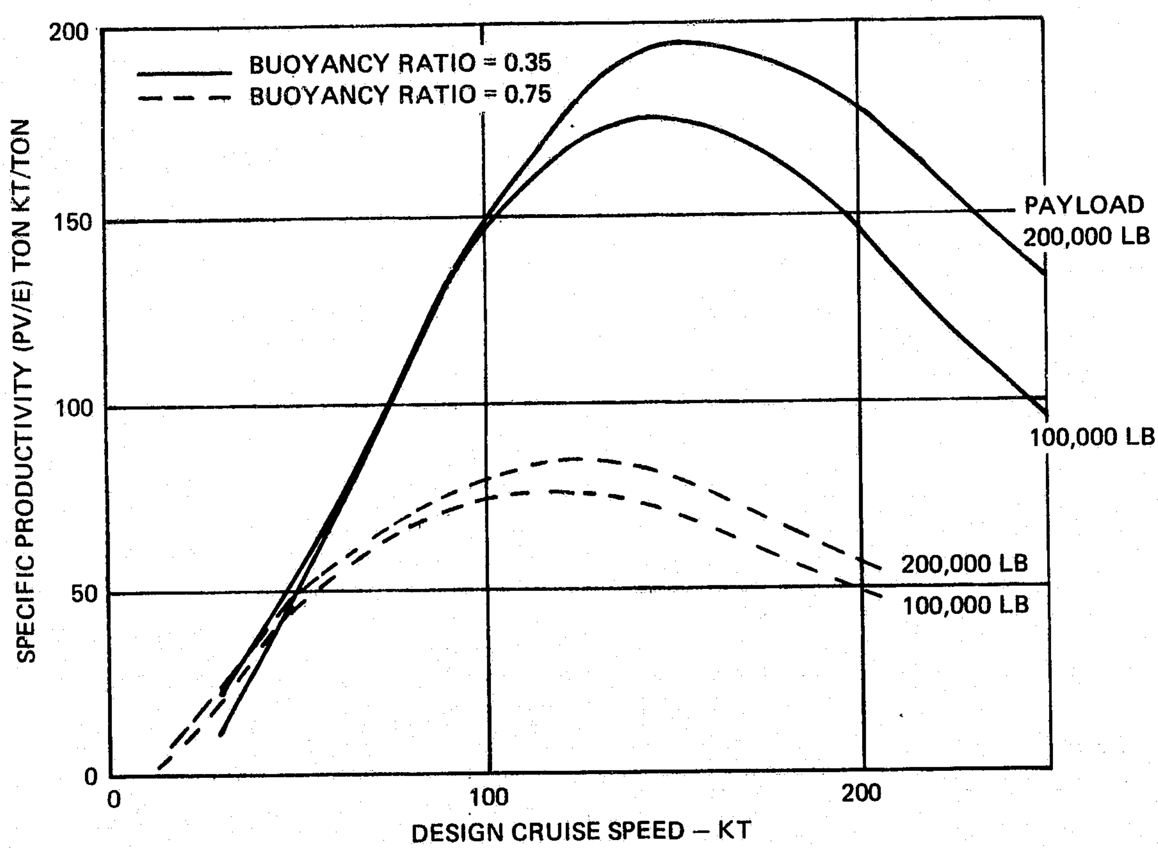
1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

Figure 5–84. Hybrid Airship Trend Study – Dynairship, 300 N.M. Short Range Mission – Gross Lift Requirements

high design gross lift results (for a specified payload). As the design speed increases, the induced drag decreases, and the parasite drag increases. The interplay of these two factors and their effect on the fuel and power required to perform a given mission is responsible for the gross lift reaching a minimum and then increasing again with increased speed. At a buoyancy ratio of 0.75, the curve shape is similar except that the larger volume requirements of the hull result in increased parasite drag, increased structural weight, increased power requirements, and, therefore, a higher gross lift requirement at high speed for the same payload. The effect of increasing design payload is also shown on the curve. The gross lift requirement simply moves to a higher value, but the characteristic shape is identical.

In Figure 5-85, again for the short range mission, specific productivity is shown as a function of design speed. For a buoyancy ratio of 0.35, the specific productivity reaches a maximum (for both payloads) at approximately 150 kts. This implies that the weight empty fraction is decreasing up to that speed. At higher speeds, the weight empty fraction increases as specific productivity decreases. The increase in weight empty fraction above 150 kt (77.17 m/s) can be attributed to the increase of parasite drag with speed. This requires higher installed power and, therefore, more fuel. In addition, the structure weight increases because of the higher dynamic pressure. The results are similar for the 0.75 buoyancy ratio, except the specific productivity is less because of a higher weight empty fraction. The peak specific productivity for the .75 buoyancy ratio of 0.35 gives a higher specific productivity than the 0.75 ratio.

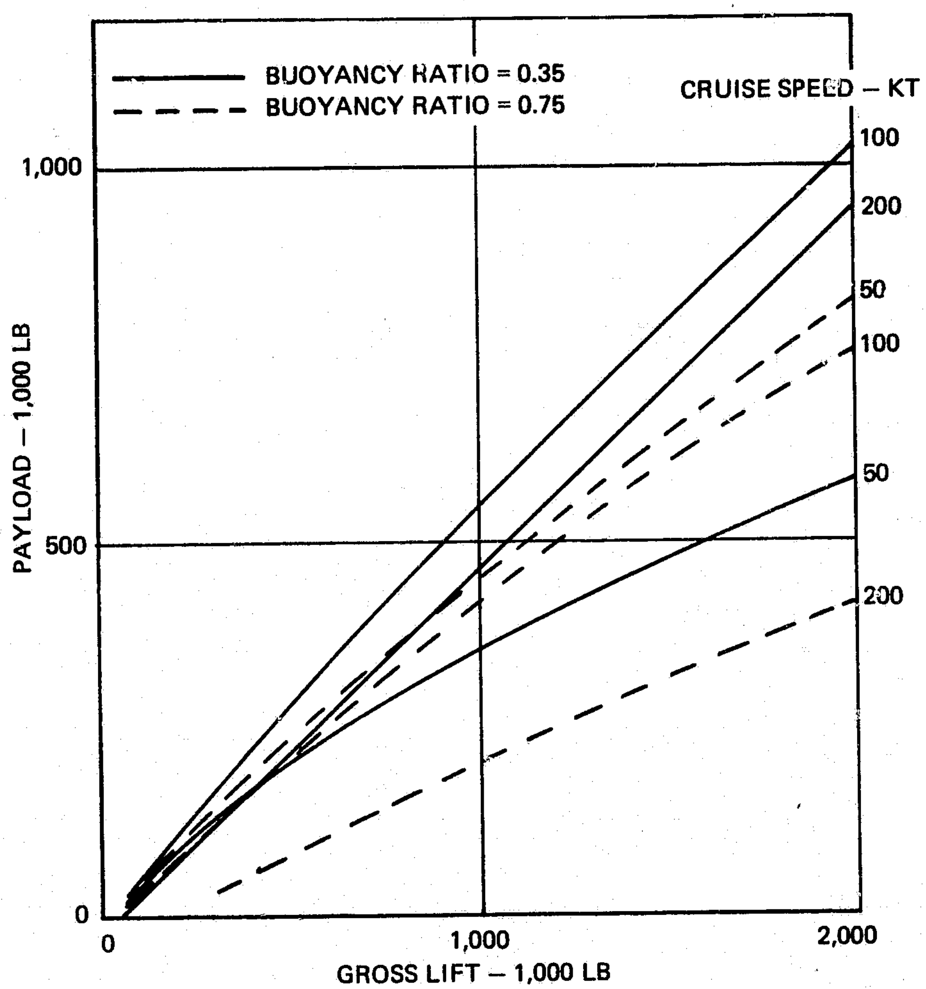
Figure 5-86 shows the tradeoff between payload and gross lift for buoyancy ratios of 0.75 and 0.35 and for speeds of 50, 100 and 200 kts. This data shows that the ratio of payload to gross lift for a constant speed is virtually constant within the range of parameters considered. Figure 5-87 shows the weight empty and mission fuel required as a function of gross lift, buoyancy ratio and speed. From these data, the ratio



CONVERSION FACTORS:

1 LB = 0.454 KG
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

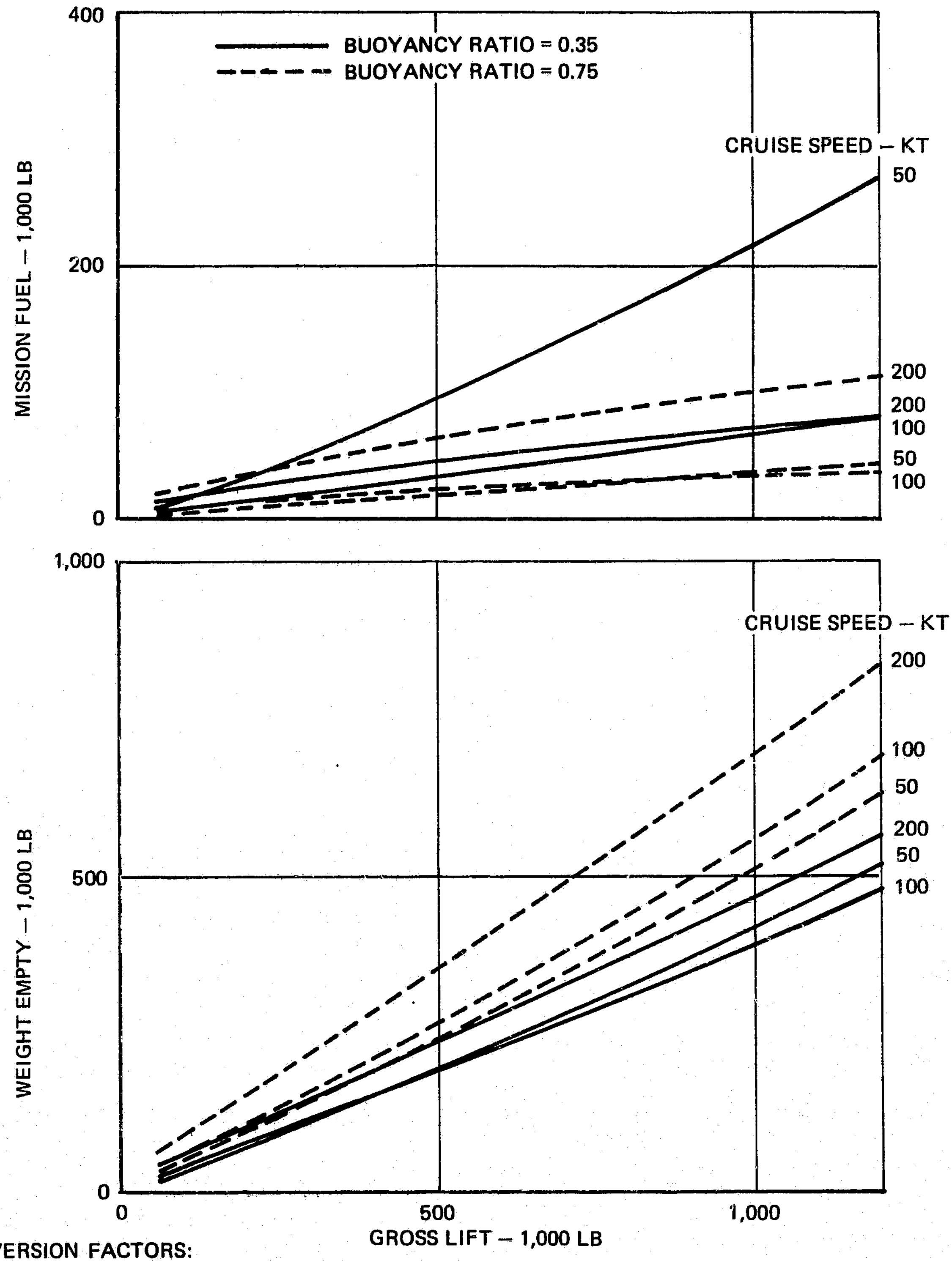
Figure 5–85. Hybrid Airship Trend Study – Dynairship, 300 N.M. Short Range Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

Figure 5–86. Hybrid Airship Trend Study – Dynairship, 300 N.M. Short Range Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

Figure 5–87. Hybrid Airship Trend Study – Dynairship, 300 N.M. Short Range Mission – Mission Performance

of weight empty and mission fuel with gross lift is almost constant. Figure 5-88 shows the installed power and hull volume required for each gross lift for the short range mission at the specified speeds and buoyancy ratios. It should be pointed out that the data from Figures 5-86 to 5-88 were used in constructing the gross lift and specific productivity versus speed data.

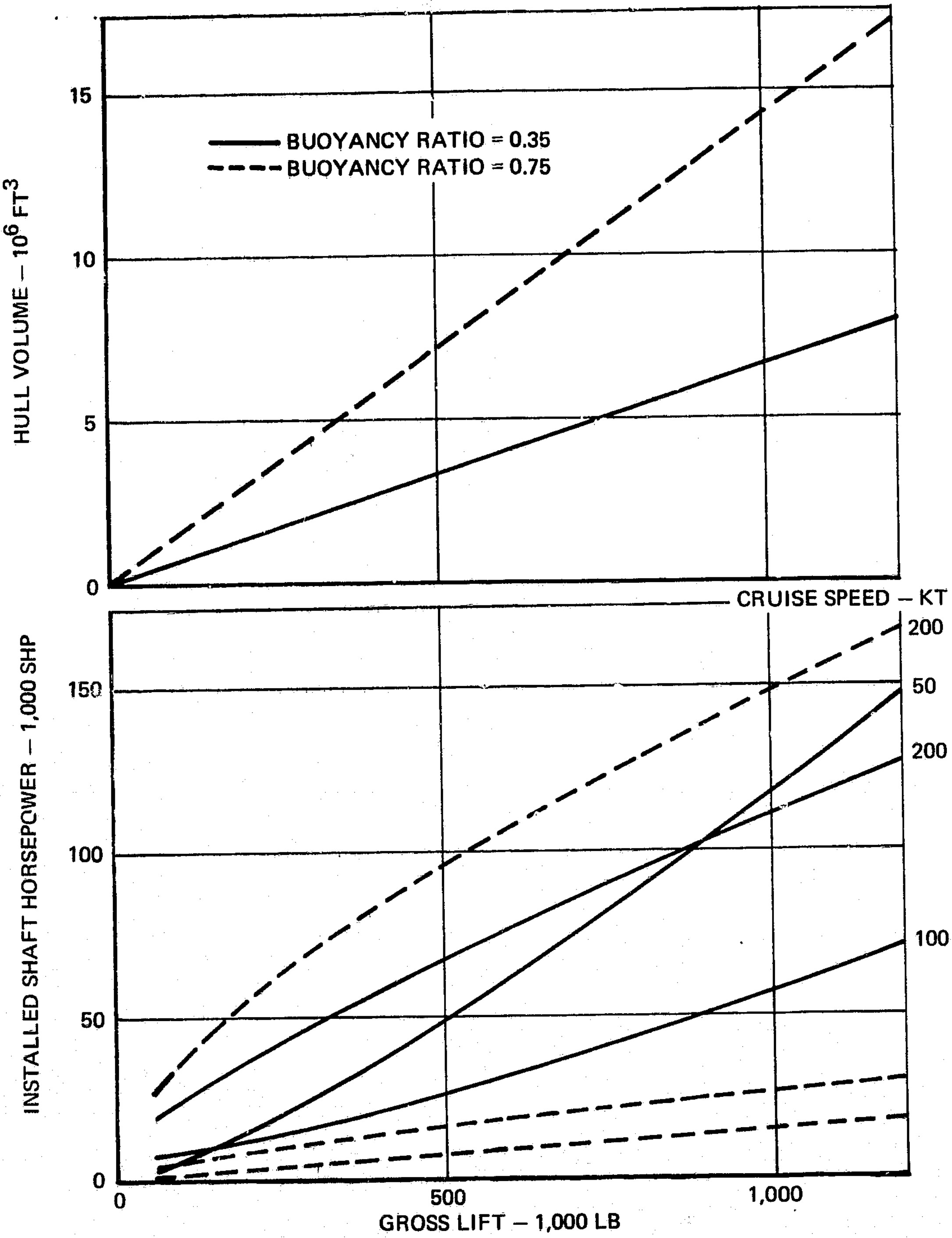
Figures 5-89 through 5-93 show the same data for the 2000 N.M. (3,704 km) transcontinental mission. The remarks made previously for the short range mission apply equally well to the longer range mission. Data computed for the Dynairship flying the 5000 N.M. (9,260 km) continental mission shows that the fuel requirement is excessive for the range of gross lifts, speeds and buoyancy ratios studied. Fuel required was always greater than fuel available. This implies that no real configuration exists with the desired mission capability under the ground rules and constraints of this parametric study. It is conceivable that Dynairships cruising at higher speeds and weights could perform the required mission.

Comparison of Figures 5-84 and 5-89 shows that the minimum gross lift required for the 200,000 (90,800 kg) payload increases with range. This is because of the increased fuel requirement for the longer range requiring an increase in airship size. The minimum gross lift occurs at lower speeds for the 2000 N.M. (3,704 km) transcontinental mission.

In comparing the speeds where the optimum specific productivity values occur in Figures 5-85 and 5-90, the optimum at 0.75 buoyancy ratio at 2000 N.M. (3,704 km) for the short range (130 kt vs 75 kt) (66.88 vs 35.58 m/s). This is primarily due to the increase in hull size and, therefore, weight and installed power, due to operation at high altitude.

5.4.3.4 Megalifter Parametric Results

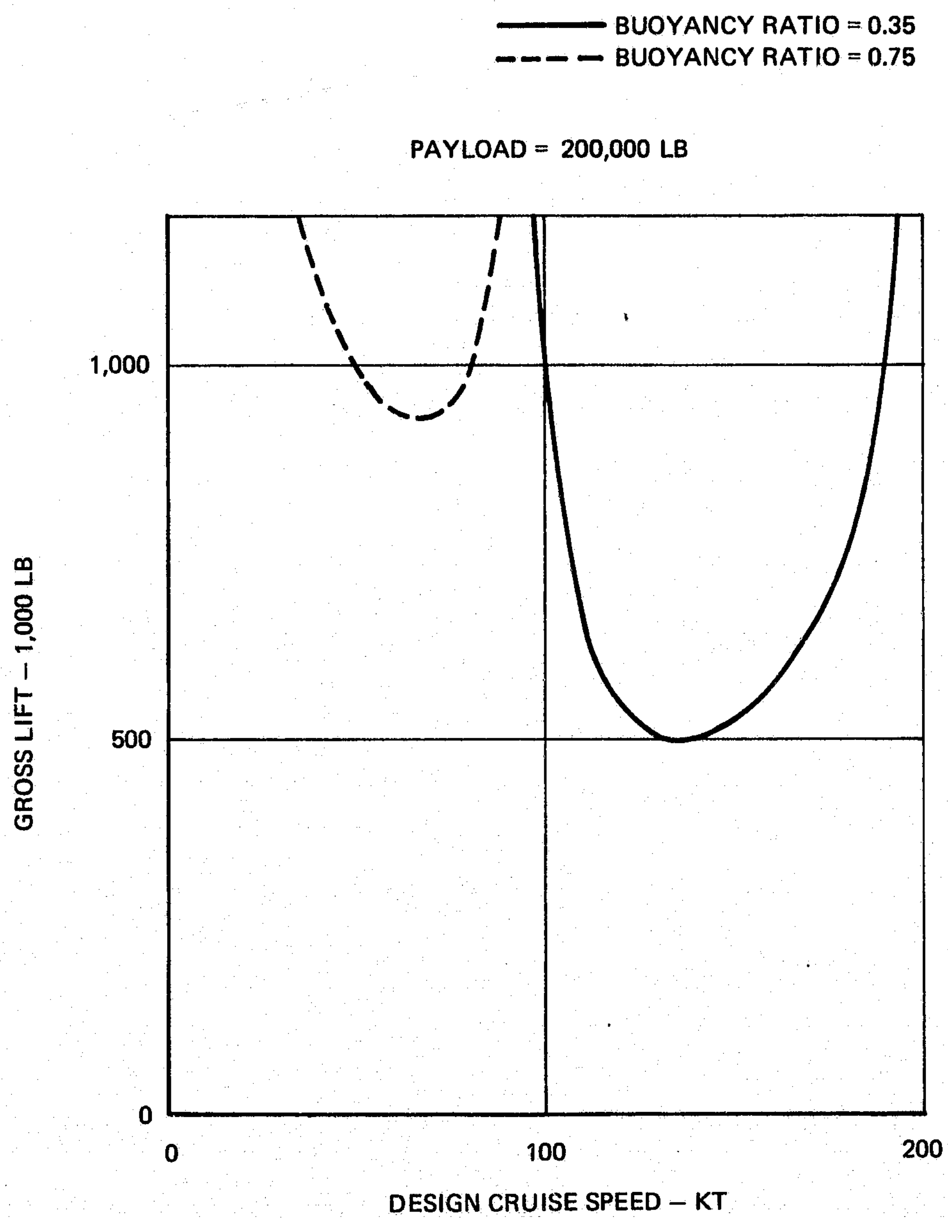
Figures 5-94 through 5-108 show the performance and sizing data for the Megalifter concept. Figures



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
300 N.M. = 555.6 KM

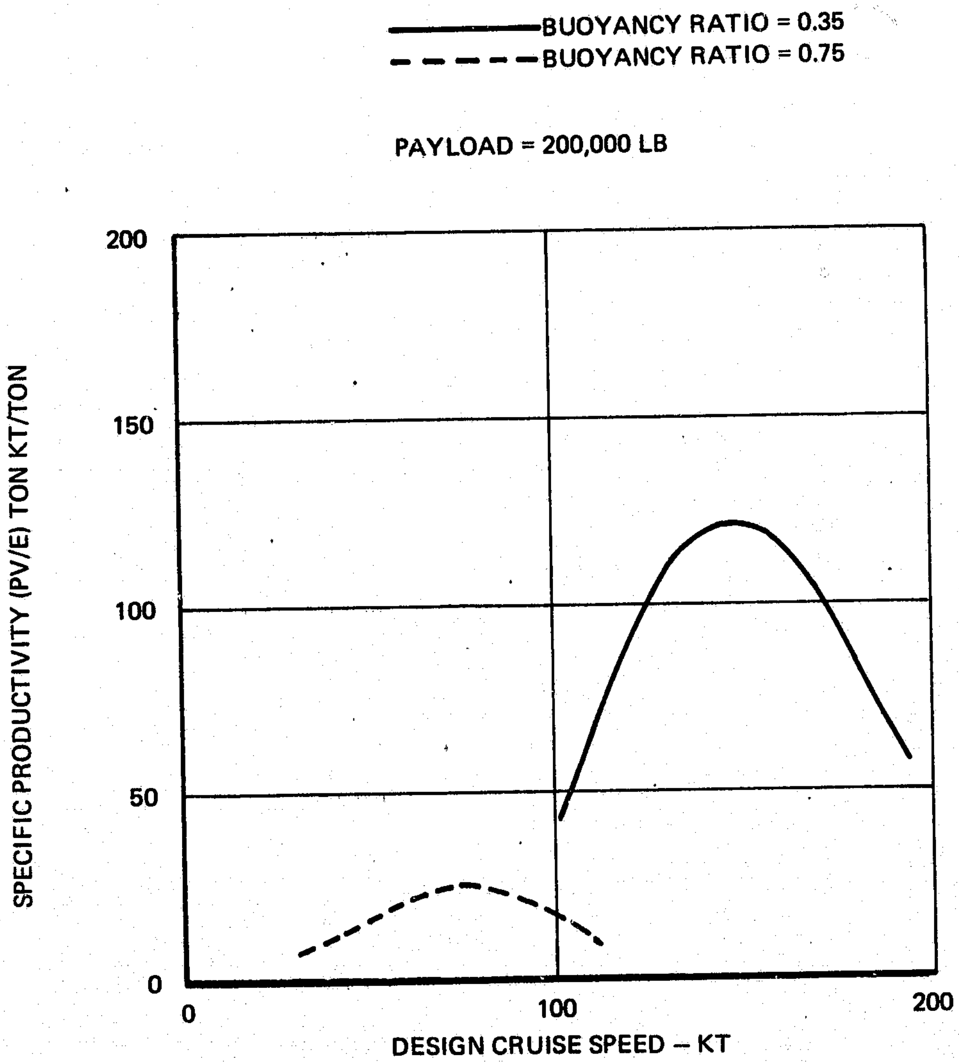
Figure 5–88. Hybrid Airship Trend Study – Dynairship, 300 N.M. Short Range Mission – Configuration Definition



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

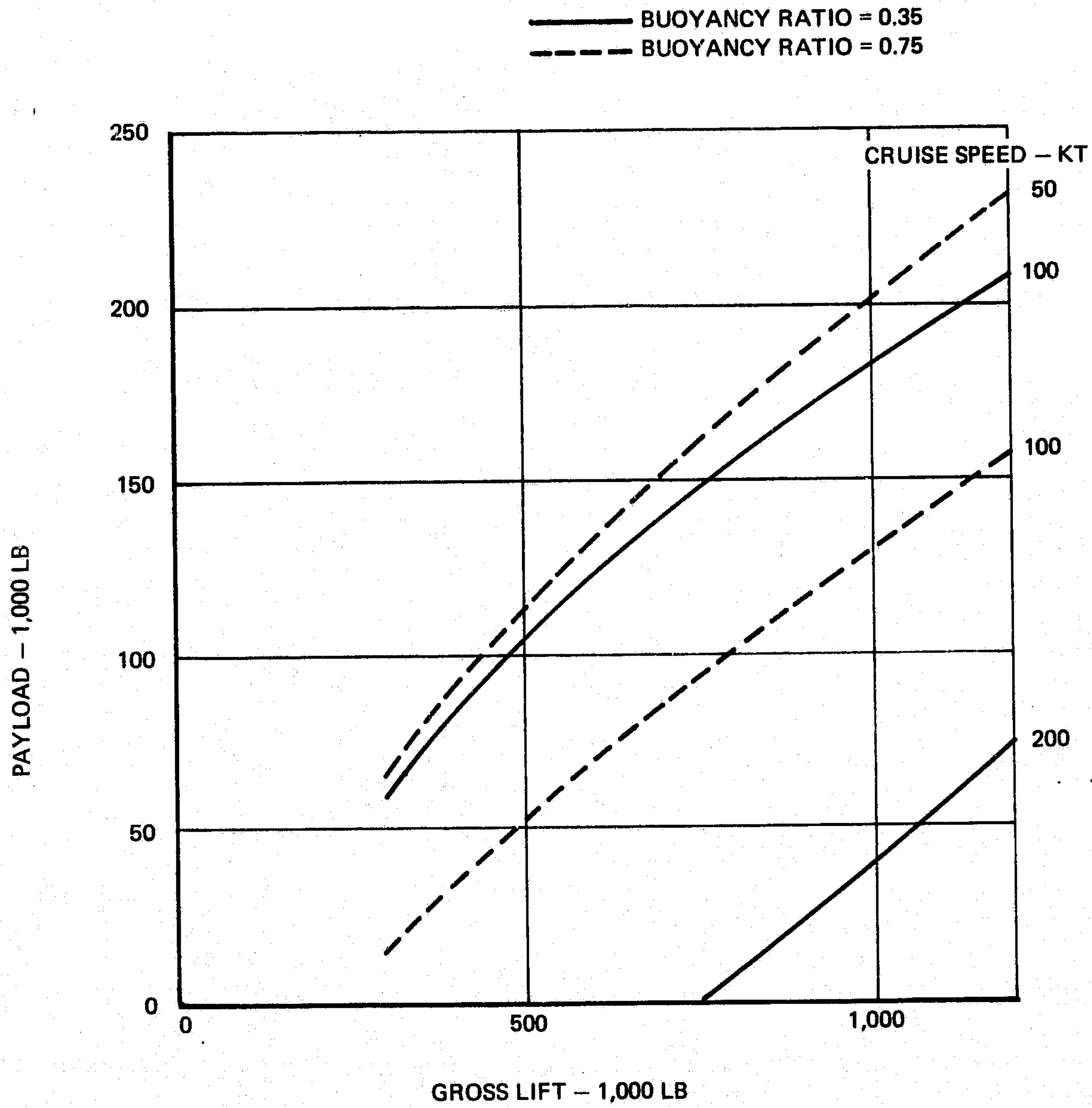
Figure 5–89. Hybrid Airship Trend Study – Dynairship, 2,000 N.M. Transcontinental Mission – Gross Lift Requirements



CONVERSION FACTORS:

1 LB = 0.454 KG
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

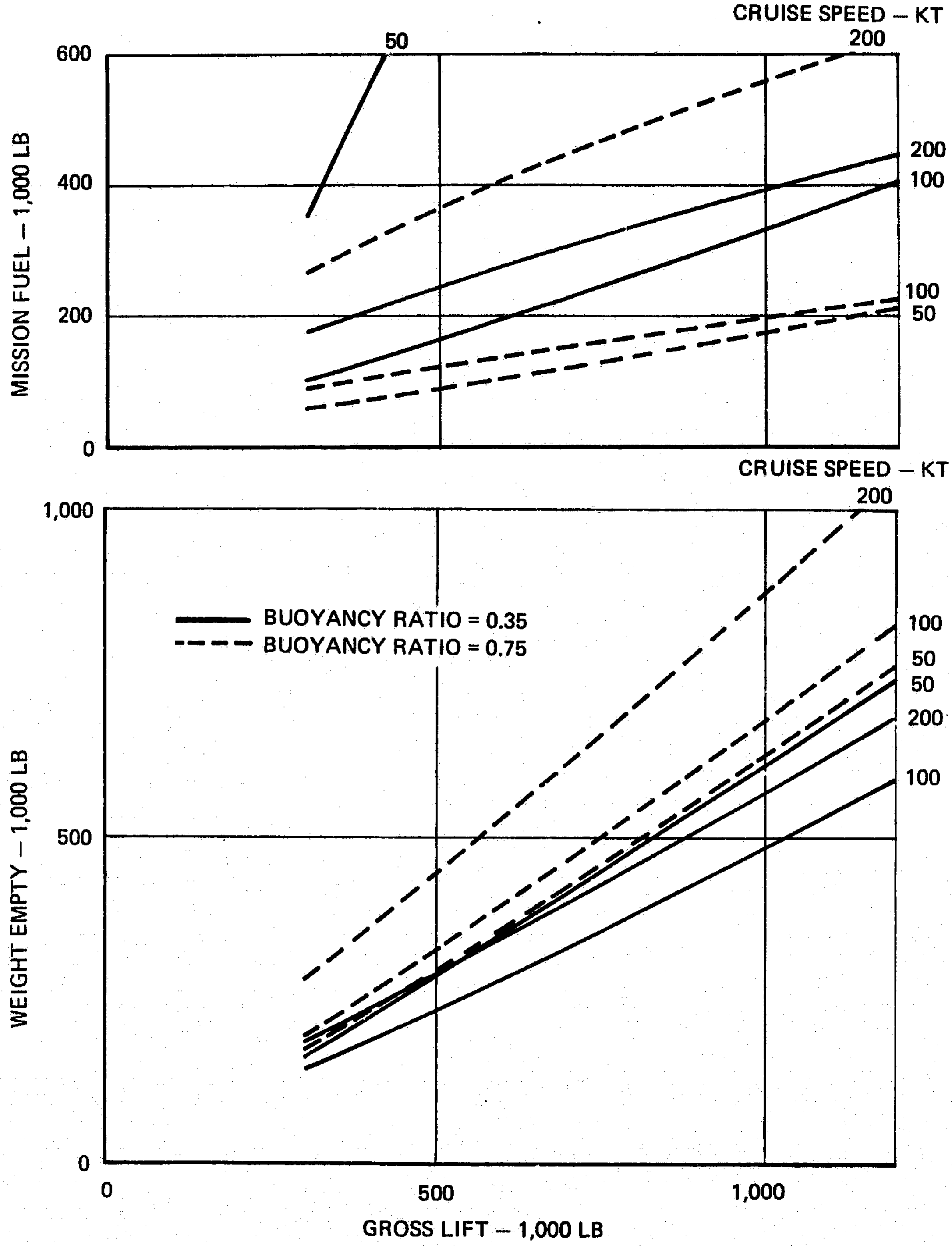
Figure 5–90. Hybrid Airship Trend Study – Dynairship, 2,000 N.M. Transcontinental Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

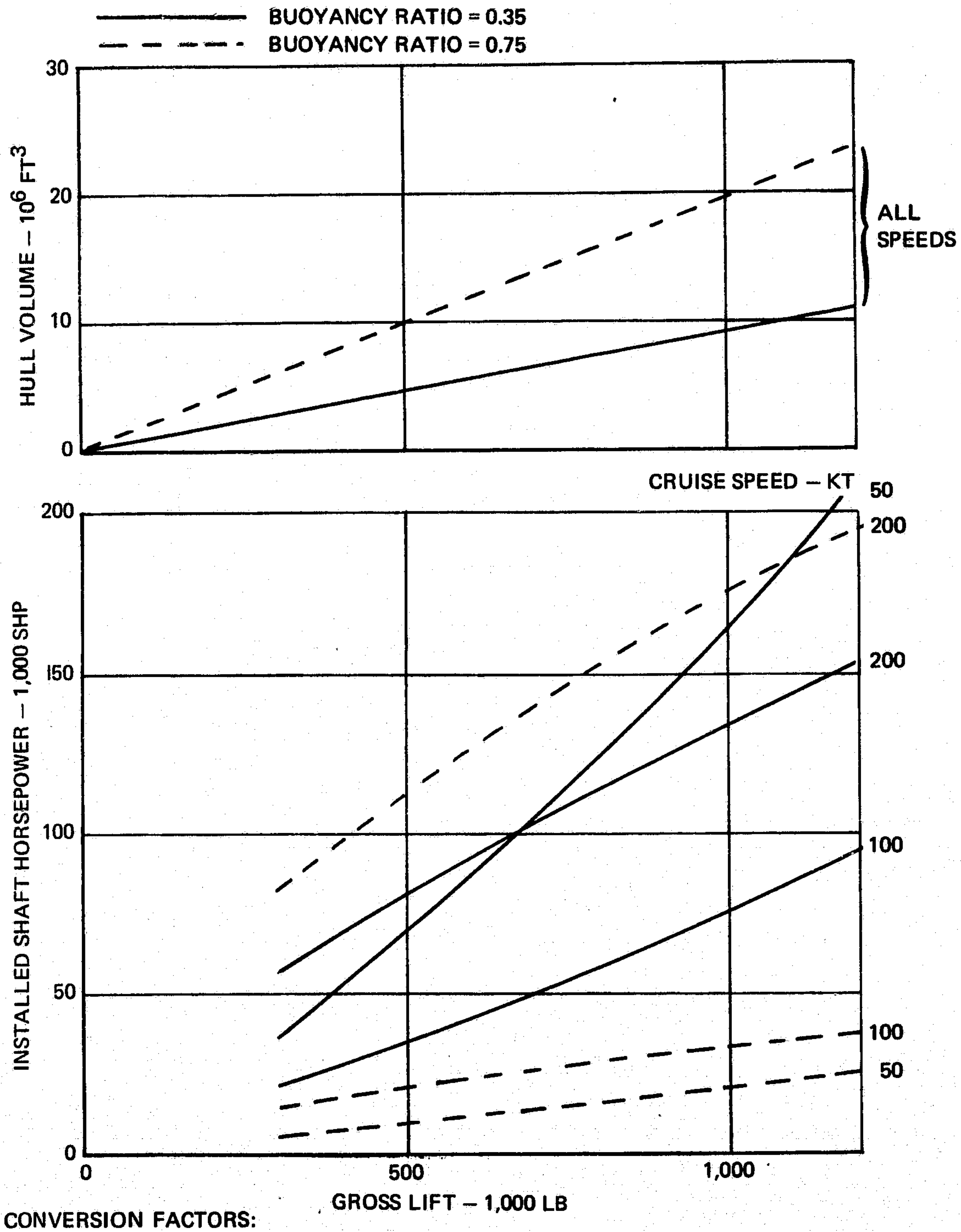
Figure 5–91. Hybrid Airship Trend Study – Dynairship, 2,000 N.M. Transcontinental Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

Figure 5–92. Hybrid Airship Trend Study – Dynairship, 2,000 N.M. Transcontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
2,000 N.M. = 3,704 KM

Figure 5–93. Hybrid Airship Trend Study – Dynairship, 2,000 N.M. Transcontinental Mission – Configuration Definition

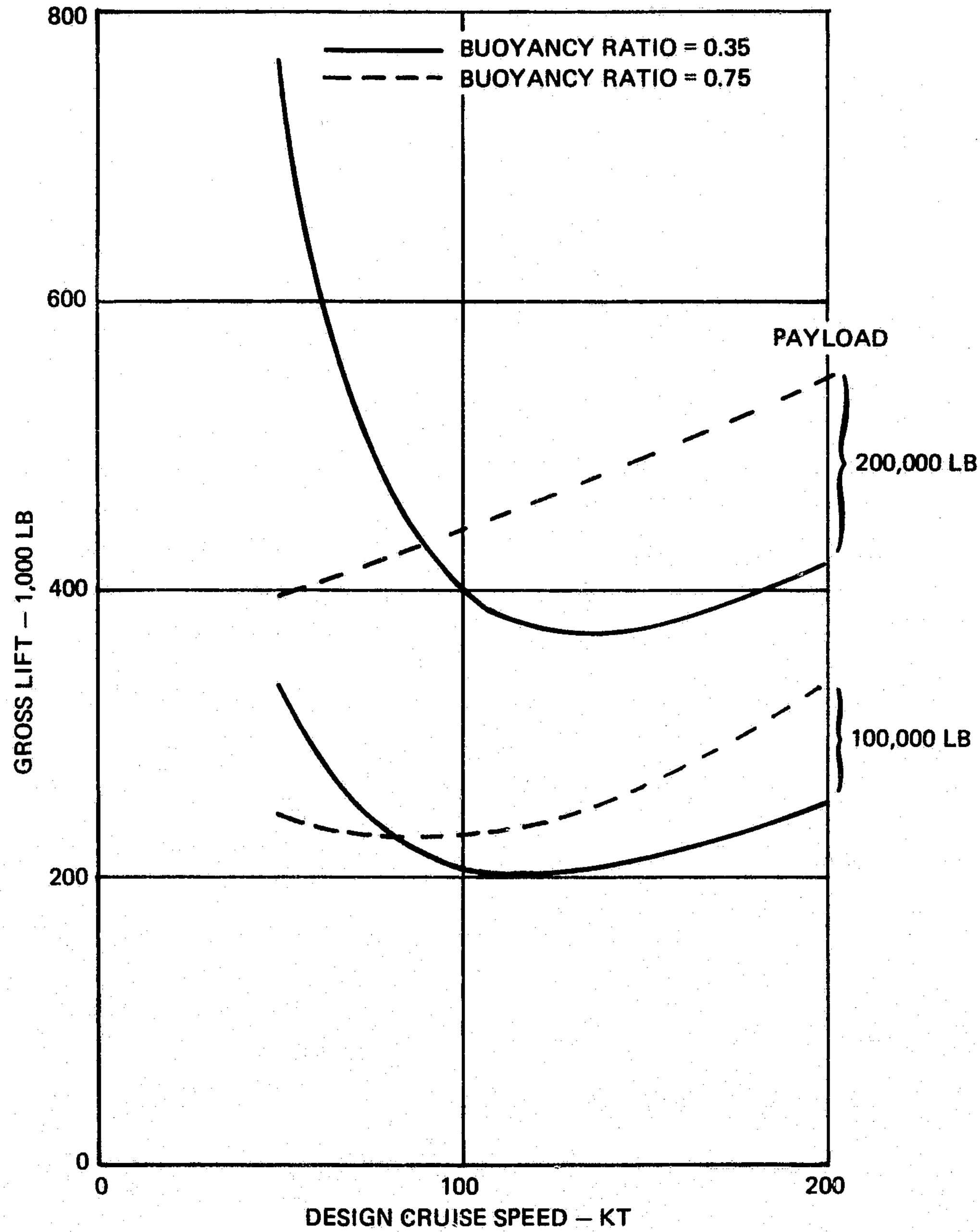
5-94 through 5-98 apply to the 300 N.M. (555.6 km) mission, Figures 5-99 through 5-103 apply to the 2000 N.M. (3,704 km) transcontinental mission, and the remainder to the 5000 N.M. (9,260 km) intercontinental mission.

The gross lift required to carry specified payloads over a range of 300 N.M. is shown in Figure for buoyancy ratios of 0.35 and 0.75. The shape of the curves is determined to a great extent by the wings. The wings for this study were designed with an aspect ratio of 11.92 and a design lift coefficient of 0.55, which is close to the value required to provide optimum lift to drag ratio at the selected aspect ratio. It should be noted that at the design condition the wing is sized to provide all of the gross lift except that part provided by the aerostatic lift of the hull. The hull provides no aerodynamic lift at the design condition.

At low values of design cruise speed, the wing is very large because it is required to provide lift at a specified value of lift coefficient with low dynamic pressure. Consequently, wings designed for such speeds are very heavy and have high drag levels. As the design speed increases, the wing size decreases rapidly and this effect is seen in Figure 5-94 at speeds below about 100 kts. At higher speeds, the parasite drag of the hull becomes predominant. The higher drag results in a greater power requirement, increased fuel consumption and these, in turn, cause increases in empty weight.

It is seen from Figure 5-94 that the minimum gross lift increases with buoyancy ratio (at least for the range of values considered) because the growth in weight and drag resulting from the increasing volume is more rapid than the reductions due to the decreasing wing size.

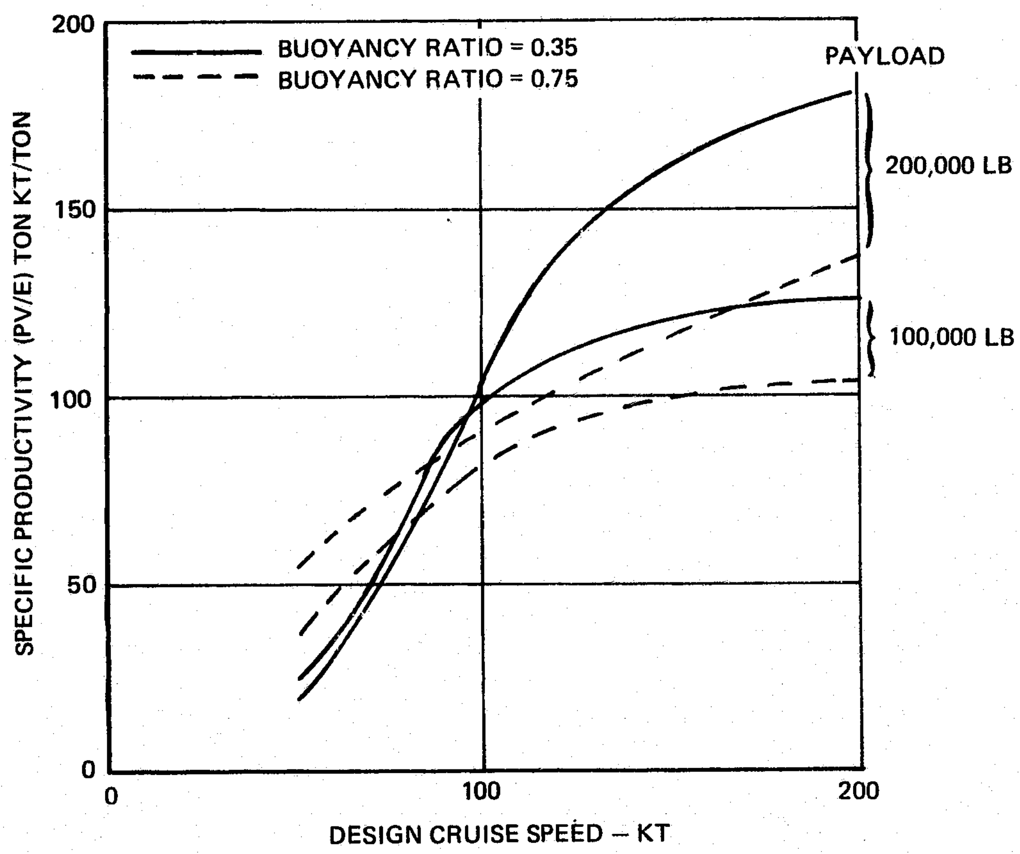
The minimum gross lift for a given payload occurs at a lower speed for the higher buoyancy ratio. This is because the wing is smaller for the higher buoyancy ratio and the induced drag of the hull is predominant at low speed.



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

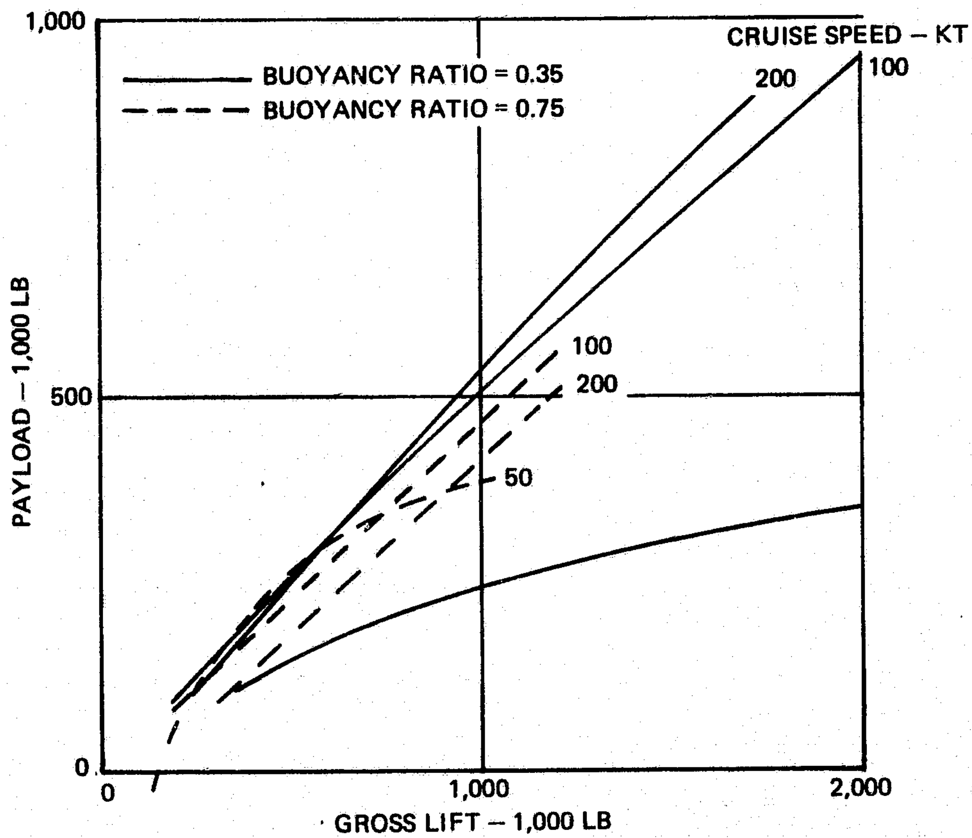
Figure 5–94. Hybrid Airship Trend Study – Megalifter, 300 N.M. Short Range Mission – Gross Lift Requirement



CONVERSION FACTORS:

1 LB = 0.454 KG
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

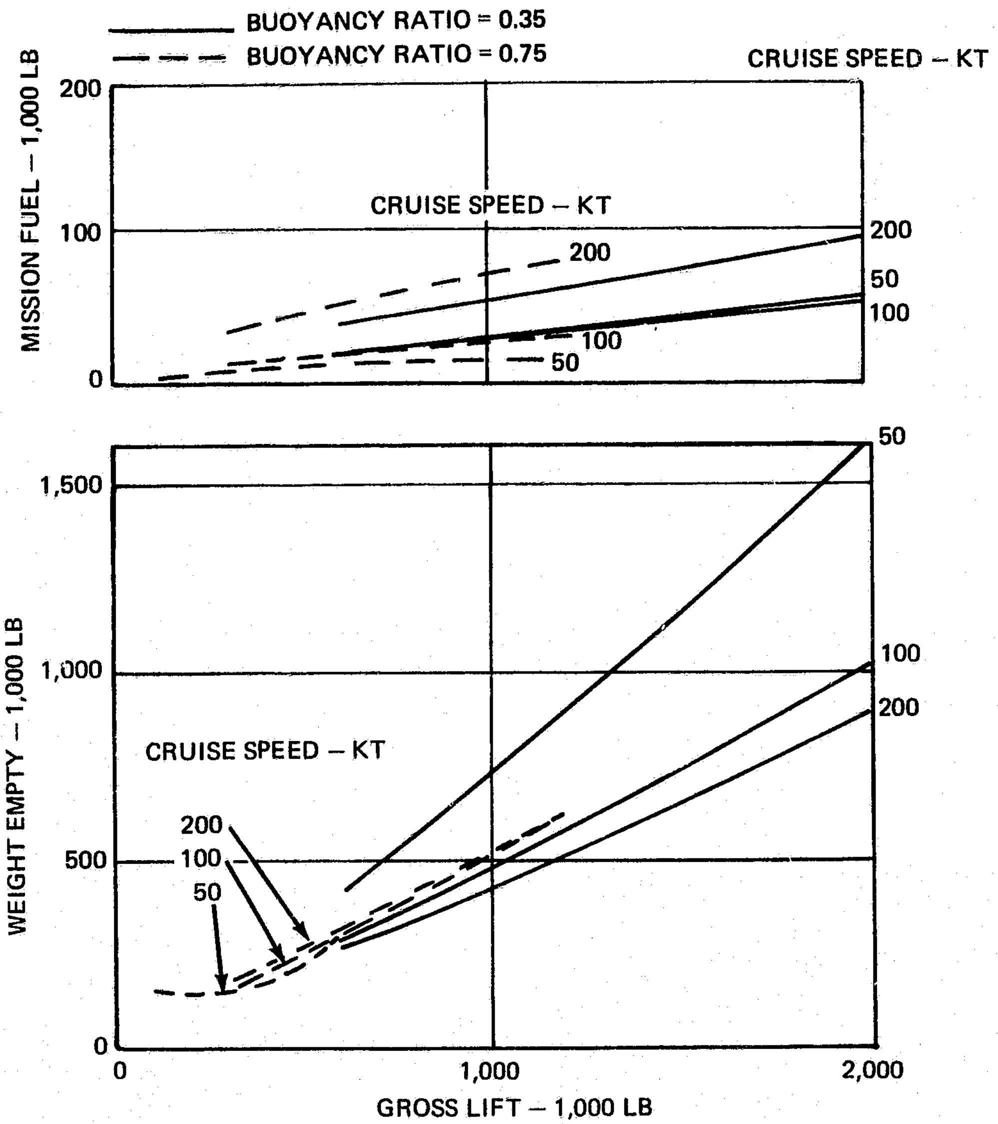
Figure 5–95. Hybrid Airship Trend Study – Megalifter, 300 N.M. Short Range Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

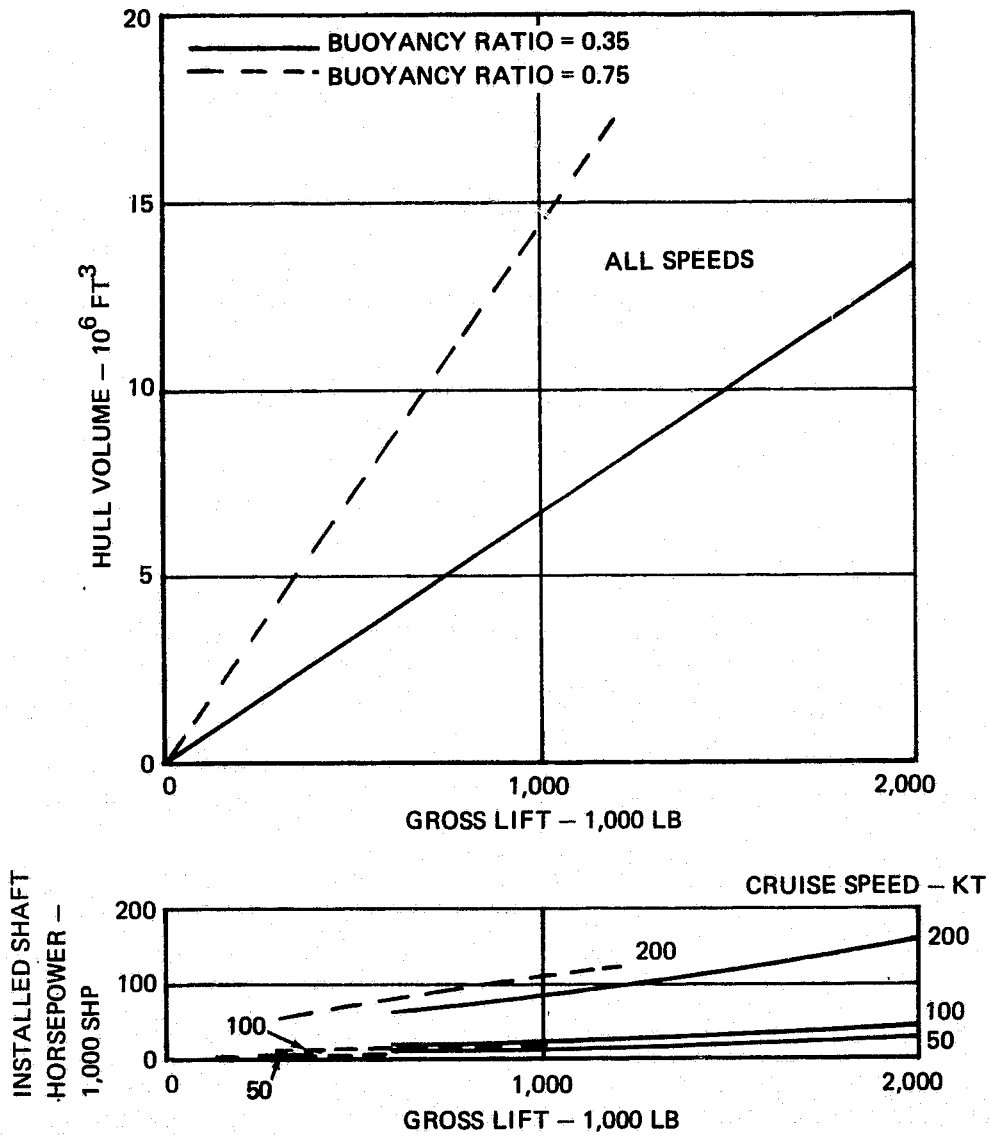
Figure 5–96. Hybrid Airship Trend Study – Megalifter, 300 N.M. Short Range Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

Figure 5–97. Hybrid Airship Trend Study – Megalifter, 300 N.M. Short Range Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
300 N.M. = 555.6 KM

Figure 5–98. Hybrid Airship Trend Study – Megalifter, 300 N.M. Short Range Mission – Configuration Definition

The effect of the wing size is also seen in that, at low cruise speeds, the required gross lift is smaller at the higher buoyancy ratio than at the lower value of 0.35.

Figure 5-95 shows the variation of specific productivity for the Megalifter for two specified payloads of 100,000 (45,400) and 200,000 (190,800 kg) lb. for the short range mission. It is seen that the optimum value of specific productivity occurs at cruise speeds greater than 200 kt (102.9 m/s) in all cases considered. It can also be seen that the specific productivity is higher at the lower value of buoyancy ratio at speeds above about 80 kts (41.2 m/s) despite the larger wing area.

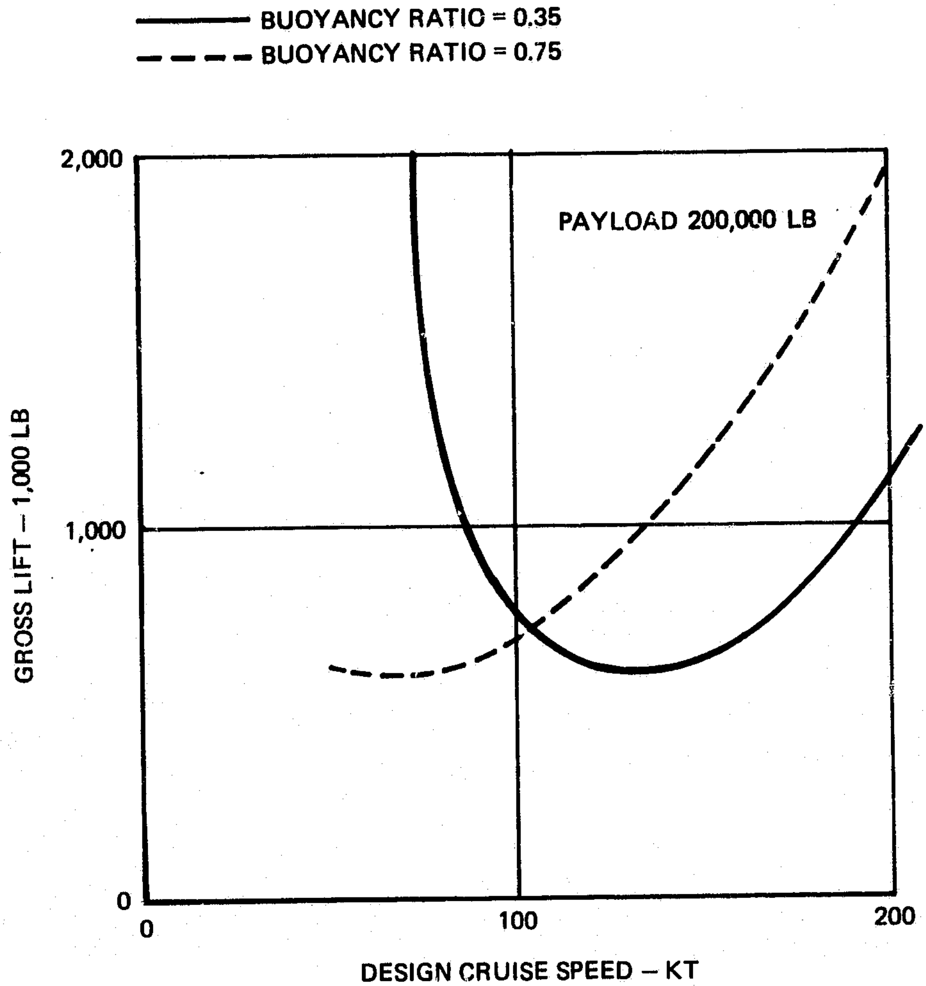
Figure 5-96 shows the payload capability as a function of speed and gross lift for buoyancy ratios of 0.35 and 0.75.

The above observations regarding the variation of weight and drag with cruise speed and buoyancy ratio are reflected in the curves of payload versus gross lift at specified cruise speeds. The payload is seen to increase steadily with gross lift for all cruise speeds, whereas at constant gross lift the variation of payload with speed shows an increase at low speeds and subsequently a decrease as an optimum speed is surpassed.

Figure 5-97 shows weight empty and mission fuel variations with gross lift and design cruise speed. Both of these quantities vary directly with the gross lift.

In Figure 5-98 the hull volume is shown as it varies with gross lift (there is no variation with design speed) together with a graph of installed power required. The rapid increase of power with cruise speed is readily apparent at all values of gross lift.

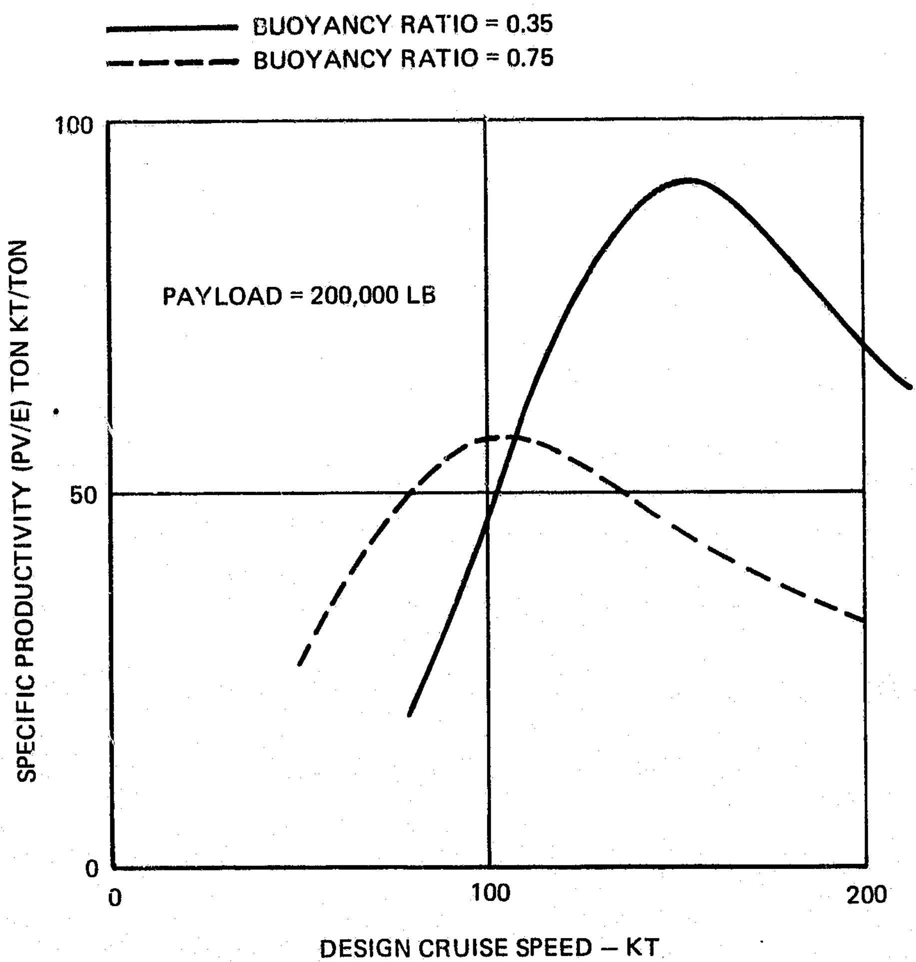
Performance data for 2000 HNM (3,704 km) range are summarized in Figure 5-99 through 5-103, while those for the 5000 HNM (9,260 km) range are shown in Figures 5-104 through 5-108. The remarks previously made regarding the effect of the wings on the airship capability apply equally well to the larger range missions.



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

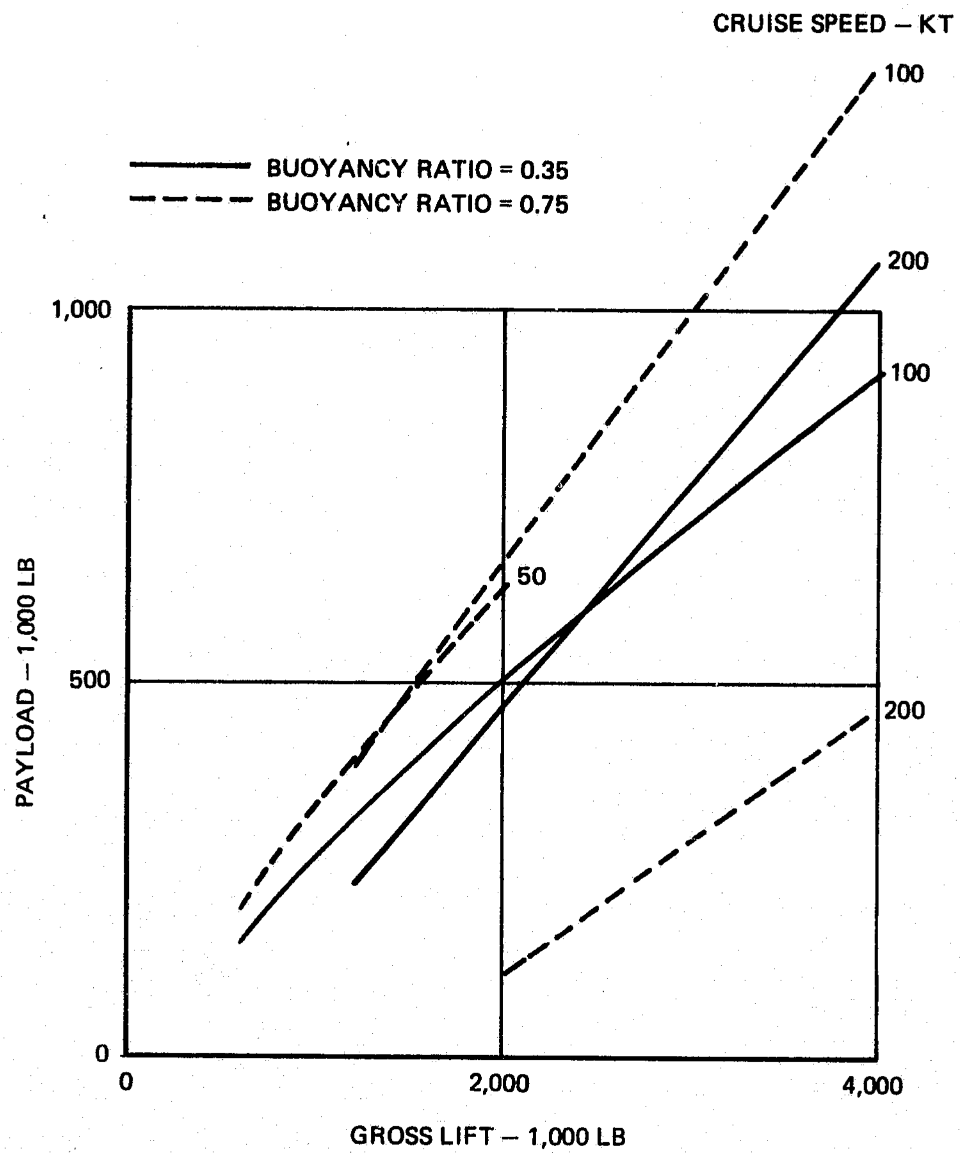
Figure 5–99. Hybrid Airship Trend Study – Megalifter 2,000 N.M. Transcontinental Mission – Gross Lift Requirement



CONVERSION FACTORS:

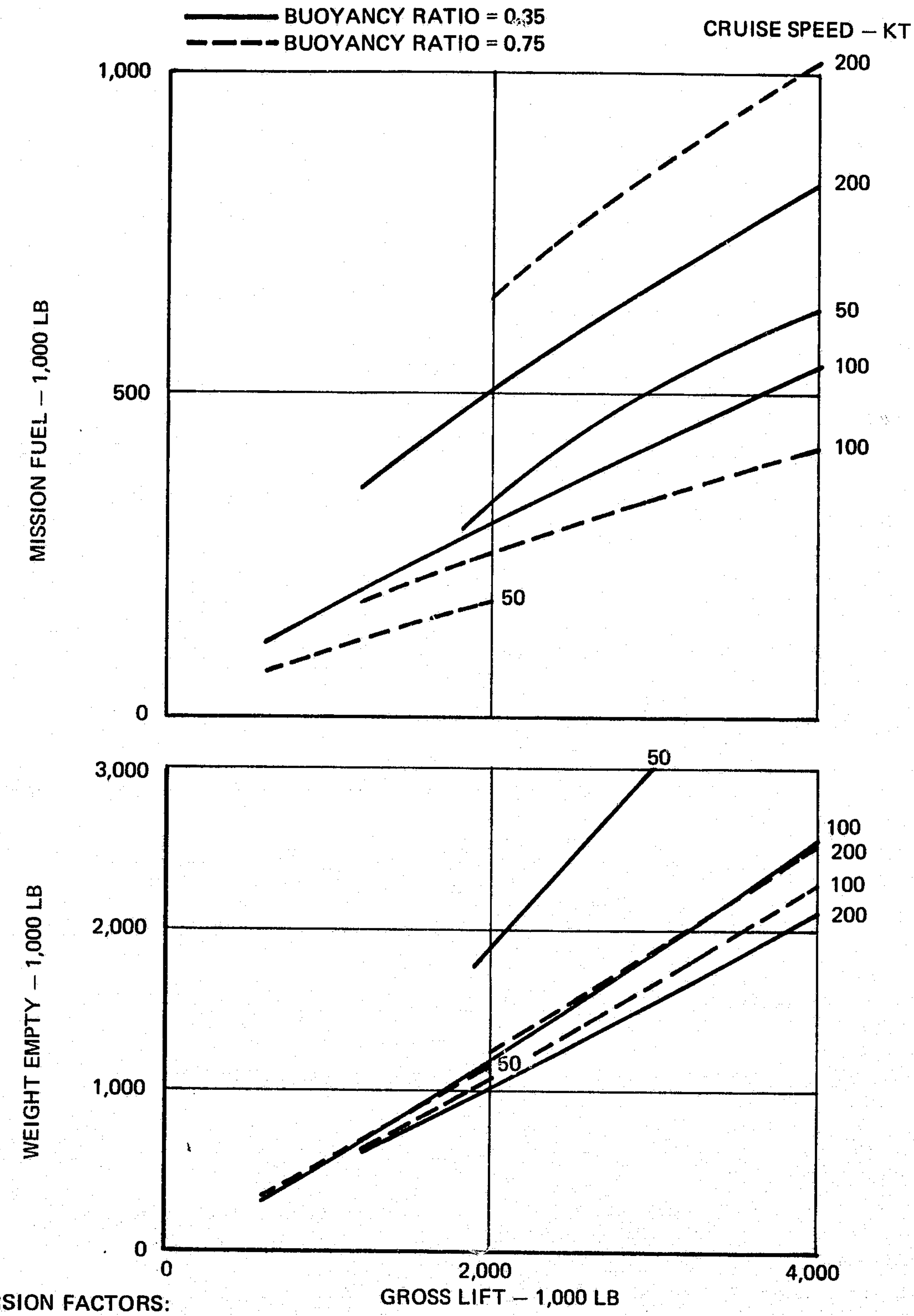
1 LB = 0.454 KG
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

Figure 5–100. Hybrid Airship Trend Study – Megalifter, 2,000 N.M. Transcontinental Mission – Specific Productivity



CONVERSION FACTORS:
1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

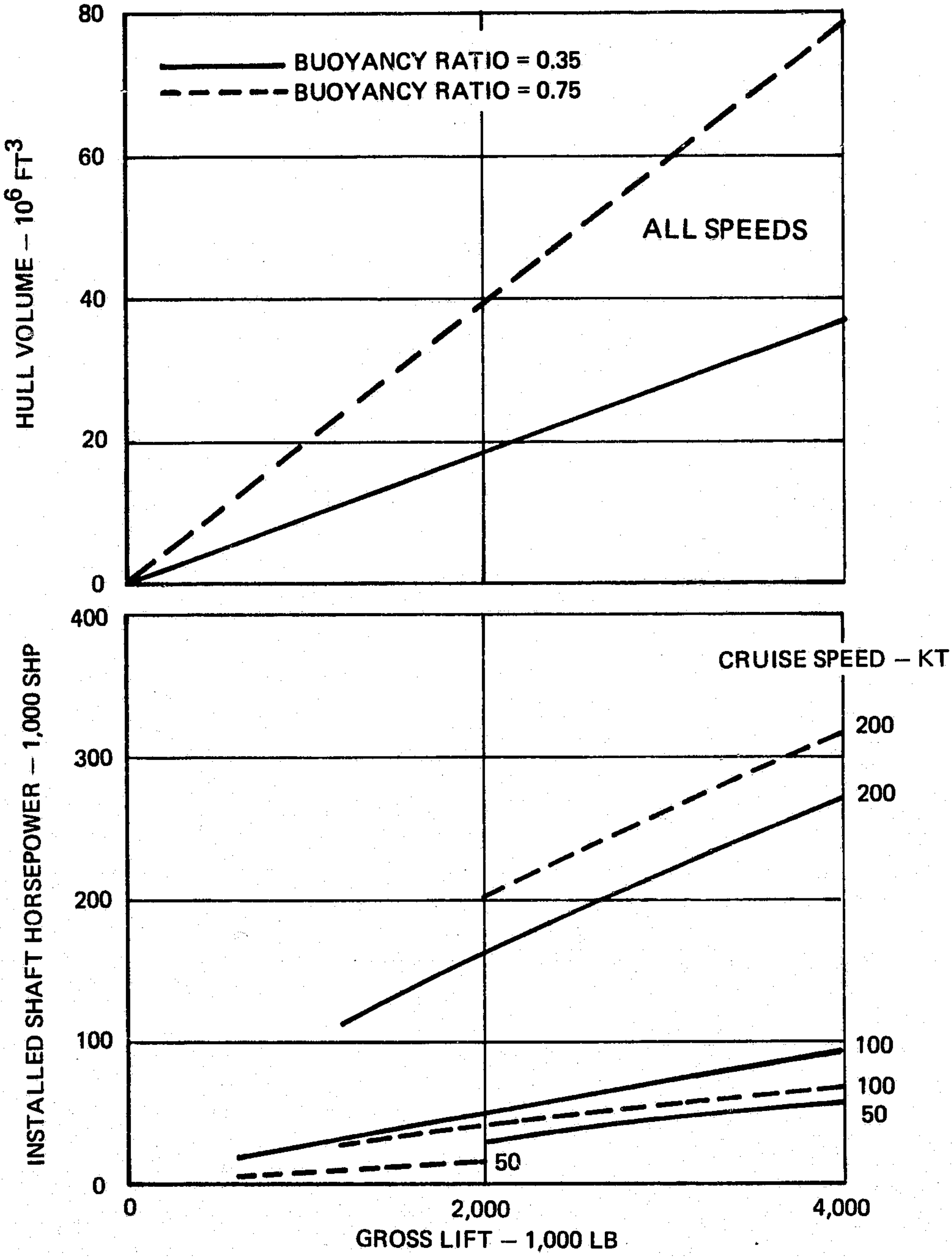
Figure 5–101. Hybrid Airship Trend Study – Megalifter, 2,000 N.M. Transcontinental Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG 1 KT = 0.514 M/S 2,000 N.M. = 3,704 KM

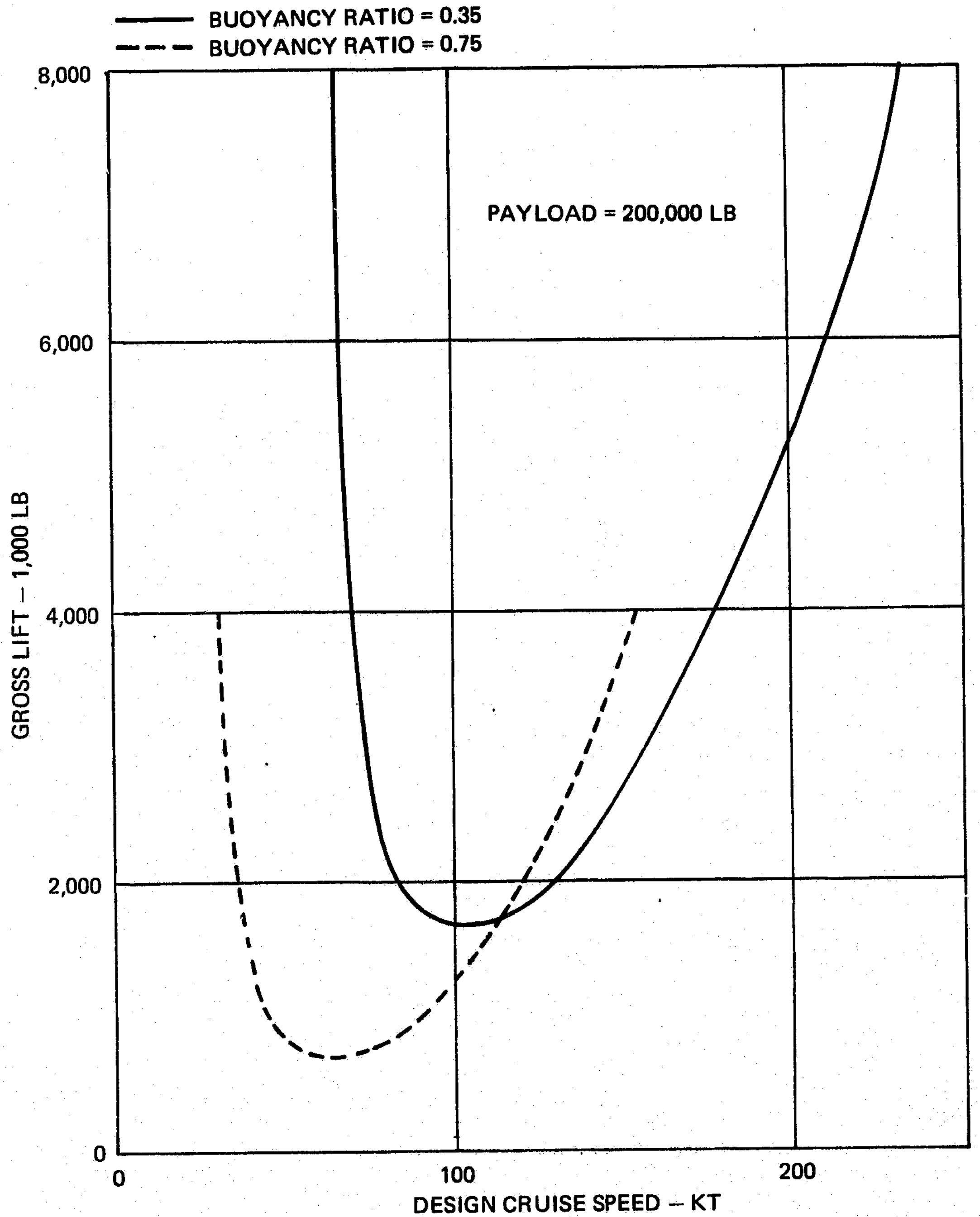
Figure 5–102. Hybrid Airship Trend Study – Megalifter, 2,000 N.M. Transcontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
2,000 N.M. = 3,704 KM

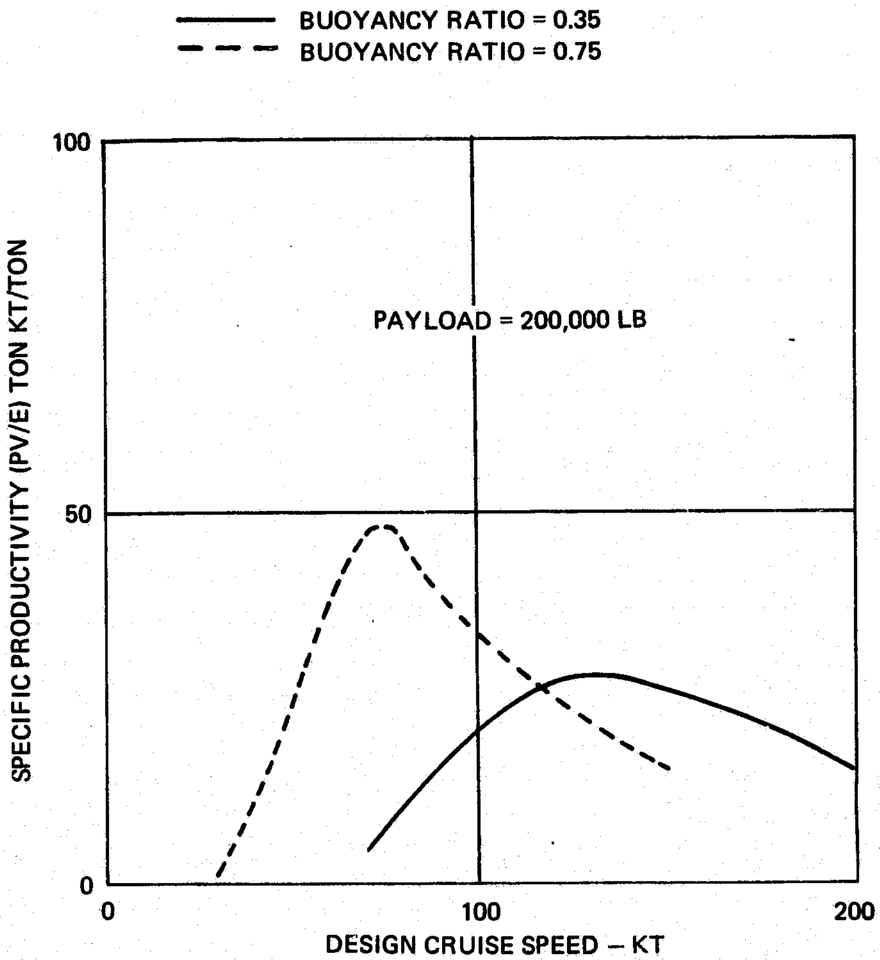
Figure 5–103. Hybrid Airship Trend Study — Megalifter, 2,000 N.M. Transcontinental Mission — Configuration Definition



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

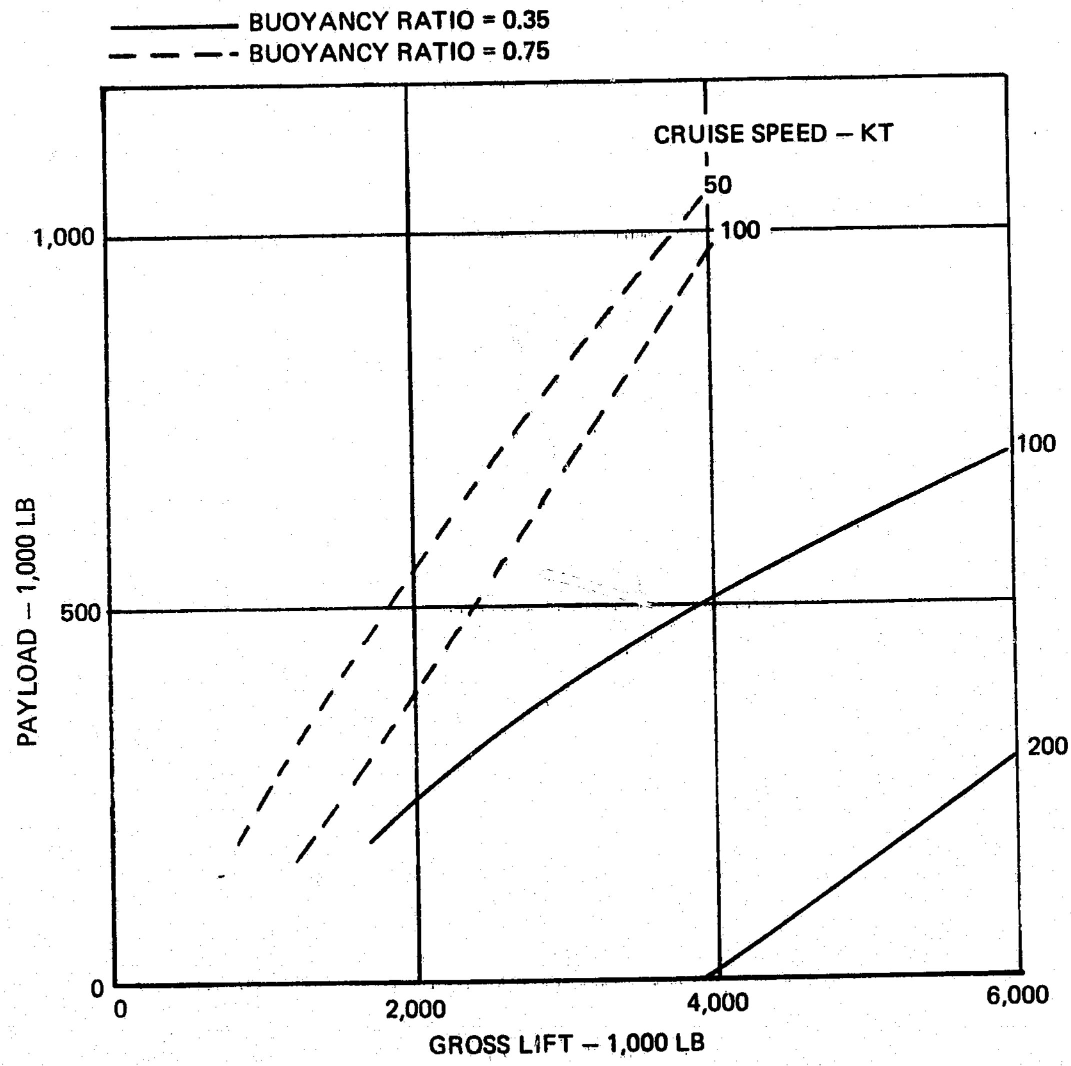
Figure 5–104. Hybrid Airship Trend Study — Megalifter, 5,000 N.M. Intercontinental Mission — Gross Lift Requirement



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 TONKT/TON = 0.514 M.TON x M/S/M.TON

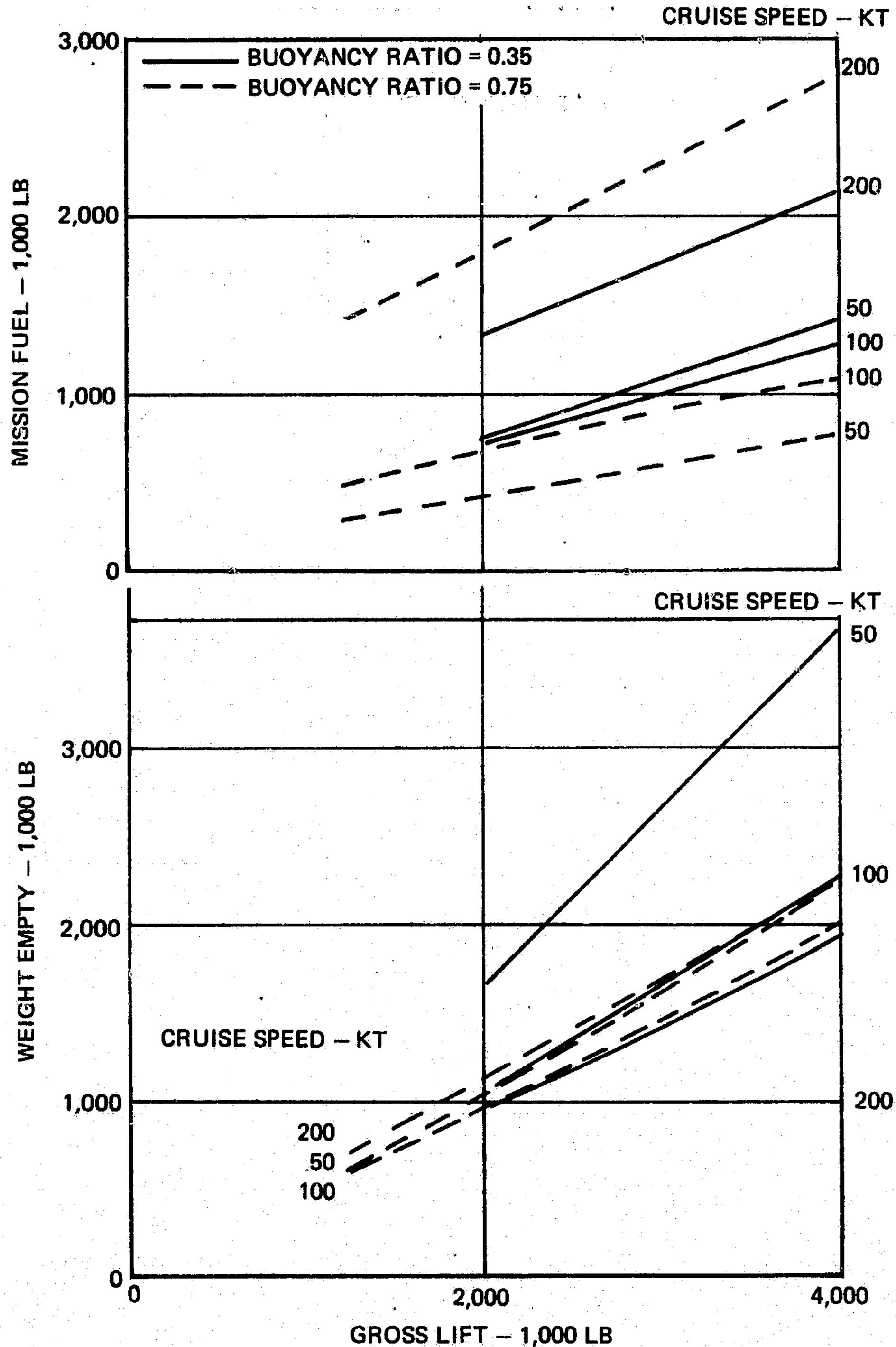
Figure 5–105. Hybrid Airship Trend Study – Megalifter, 5,000 N.M. Intercontinental Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

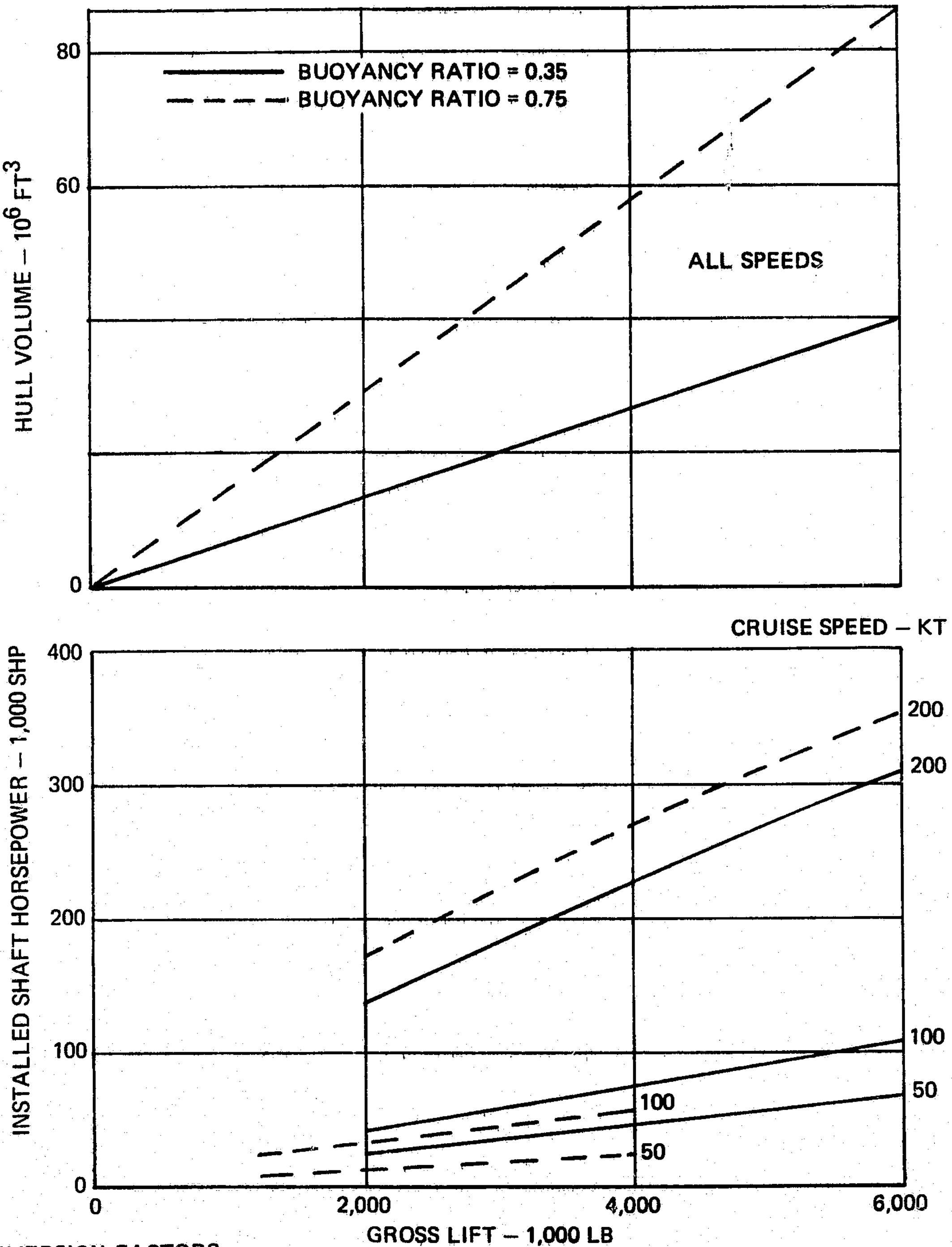
Figure 5–106. Hybrid Airship Trend Study – Megalifter, 5,000 N.M. Intercontinental Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

Figure 5–107. Hybrid Airship Trend Study – Megalifter, 5,000 N.M. Intercontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 KG
1 FT^3 = 0.0283 M^3
5,000 N.M. =9,260 KM

Figure 5–108. Hybrid Airship Trend Study – Megalifter, 5,000 N.M. Intercontinental Mission – Configuration Definition

well to the larger range missions.

Comparison of Figures 5-94, 5-99 and 5-104 shows that the minimum gross lift required for a payload of 200,000 lb (90,800 kg) increases with range. This is because of the increased fuel requirement for the long ranges entailing growth in the gross lift, size and drag of the airship.

The minimum gross lift occurs at lower speeds for the longer range missions.

It is also seen that the minimum gross lift at short range is lower at the buoyancy ratio of 0.35 than at the higher value whereas the reverse is true for the 5000 n.m. (9,260 km) mission.

In comparing the optimum specific productivity values in Figures 5-96, 5-100 and 5-105 it is to be noticed that the lower buoyancy ratio produces a higher optimum at the minimum range and a lower optimum at the 5000 n.m. (9,260 km) range. The reason is as follows: At short range the low buoyancy ratio is preferred because the airship can fly fast (the fuel requirement being only a small fraction of the gross lift) resulting in a small wing size and weight. At the longer ranges the fuel required becomes a much larger fraction of the gross lift and is minimized by flying at a lower speed where the drag is minimized. At the lower speed a larger wing is required. Increasing the buoyant lift of the hull tends to counter the effect of this wing growth.

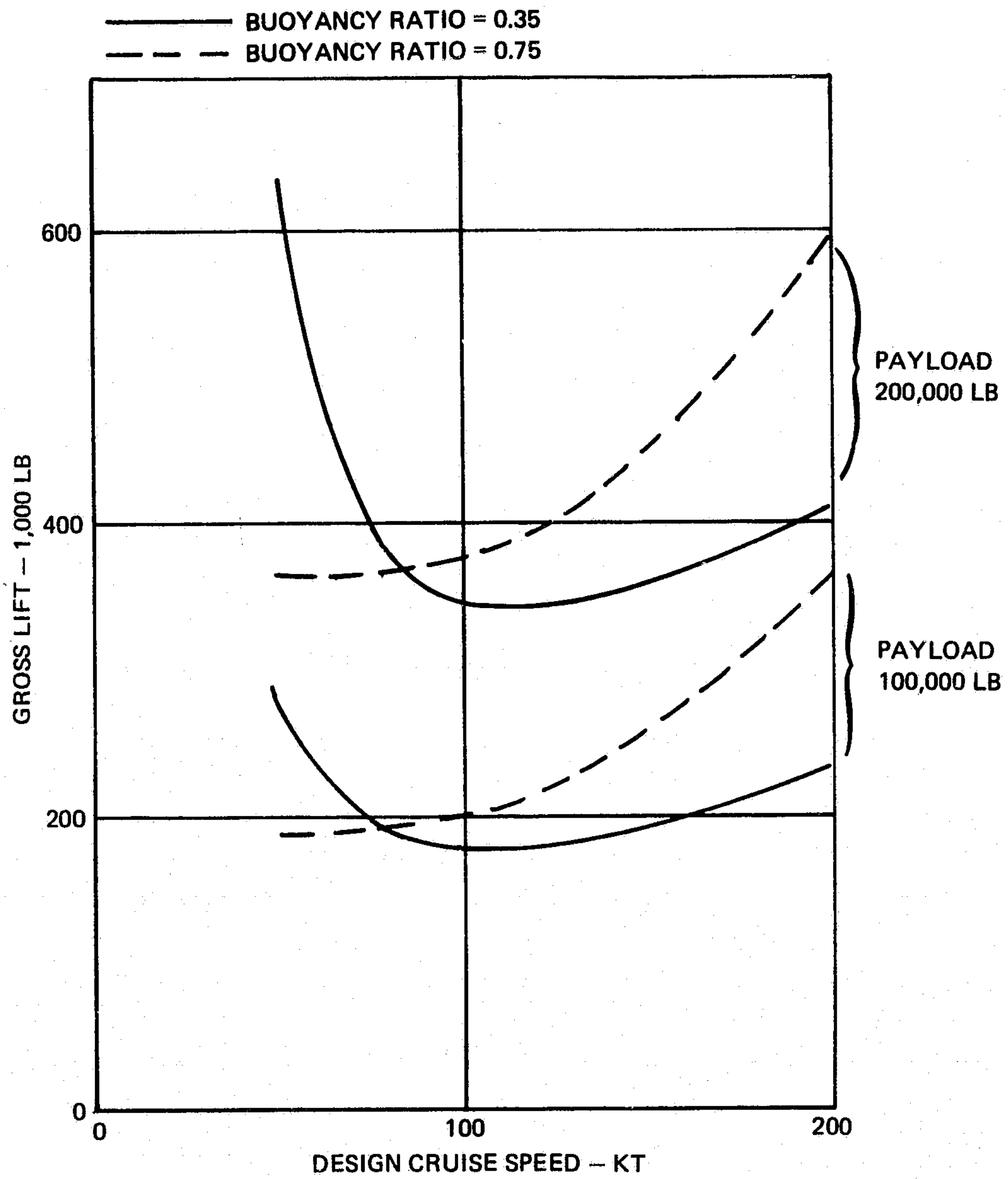
5.4.3.5 Helipsoid Parametric Results

The parametric study results of the Helipsoid lighter-than-air configuration are documented in this section. The Helipsoid, described in detail in section 5.3.1.5, is a partially buoyant concept with a low aspect ratio elliptical planform shape and a spanwise and chordwise elliptical cross section. This shape is (next to the conventional spindle-shaped hull) the most geometrically efficient from a standpoint of resultant wetted area for a given hull volume. Its main disadvantage, as is the case with all low aspect ratio lifting body shapes, is a low lift

curve slope, resulting in higher (compared to conventional high asepct ratio wings) required angles of attack (and thus higher induced drag) for a given lift coefficient.

Figure 4-109 shows gross lift as a function of design cruise speed for design payloads of $100,000 (45,400 kg) and 200,000 lbs. (90,800 kg) for the short range (300 n.m.) (556 km) mission. Buoyancy ratios of 0.35 and 0.75 are shown. These data show that, for a given payload, the buoyancy ratio of 0.35 results in a smaller, lighter configuration. The minimum gross lift configuration occurs at a speed of approximately 110 kts (56.6 m/s). The characteristic shape of the curves at a buoyancy ratio of 0.35 is attributed to the fact that at low speeds, the low aspect ratio Helipsoid has high induced drag. This means that the power and fuel required to perform the mission is high and a relatively high design gross lift results (for a specified payload). As the design speed increases, the induced drag decreases, and the parasite drag increases. The interplay of these two factors, and their effect on the fuel and power required to perform a given mission is responsible for the gross lift reaching a minimum and then increasing again with increased speed. At a buoyancy ratio of 0.75, the curve shape is similar except that the larger volume requirements of the hull result in increased parasite drag and therefore a higher gross lift requirement at high speed for the same payload, The effect of increasing design payload is also shown on the curve. The gross lift requirement simply moves to a higher value but the characteristic shape is identical.

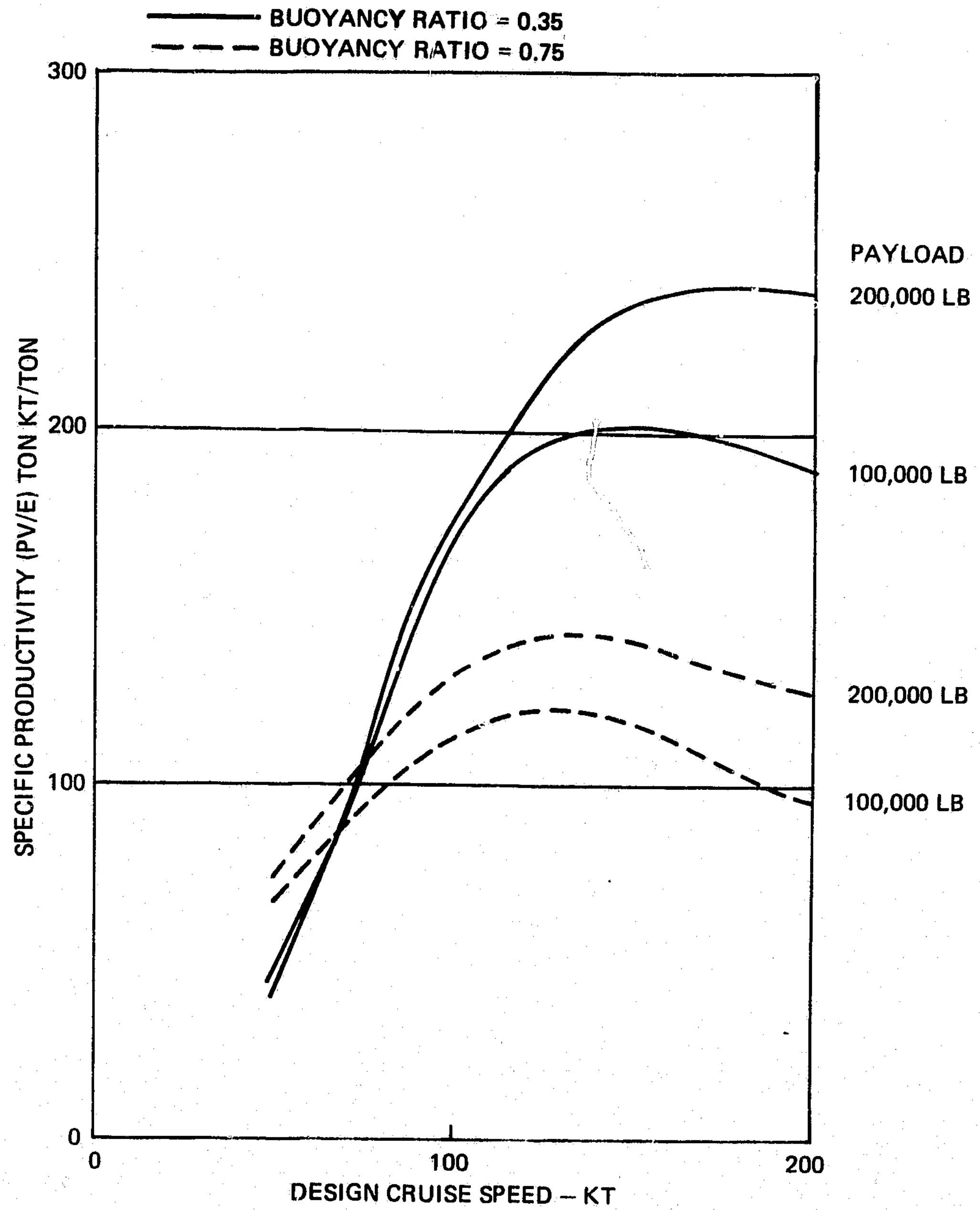
In Figure 5-110, again for the short range mission, specific productivity is shown as a function of design speed. For a buoyancy ratio of 0.35, the specific productivity reaches a maximum at approximately 150 to 180 kts (77.2 to 92.6 m/s). This implies that the weight empty fraction is decreasing up to this speed. At higher speeds, the weight empty fraction increases as specific productivity decreases. The increase in weight empty fraction above 150 kts. can be attributed to the increase of parasite drag with speed. This requires higher installed power and therefore more fuel. In addition, the structure



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

Figure 5–109. Hybrid Airship Trend Study – Helipsoid, 300 N.M. Short Range Mission – Gross Lift Requirements



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
300 N.M. = 555.6 KM

Figure 5–110. Hybrid Airship Trend Study – Helipsoid, 300 N.M. Short Range Mission – Specific Productivity

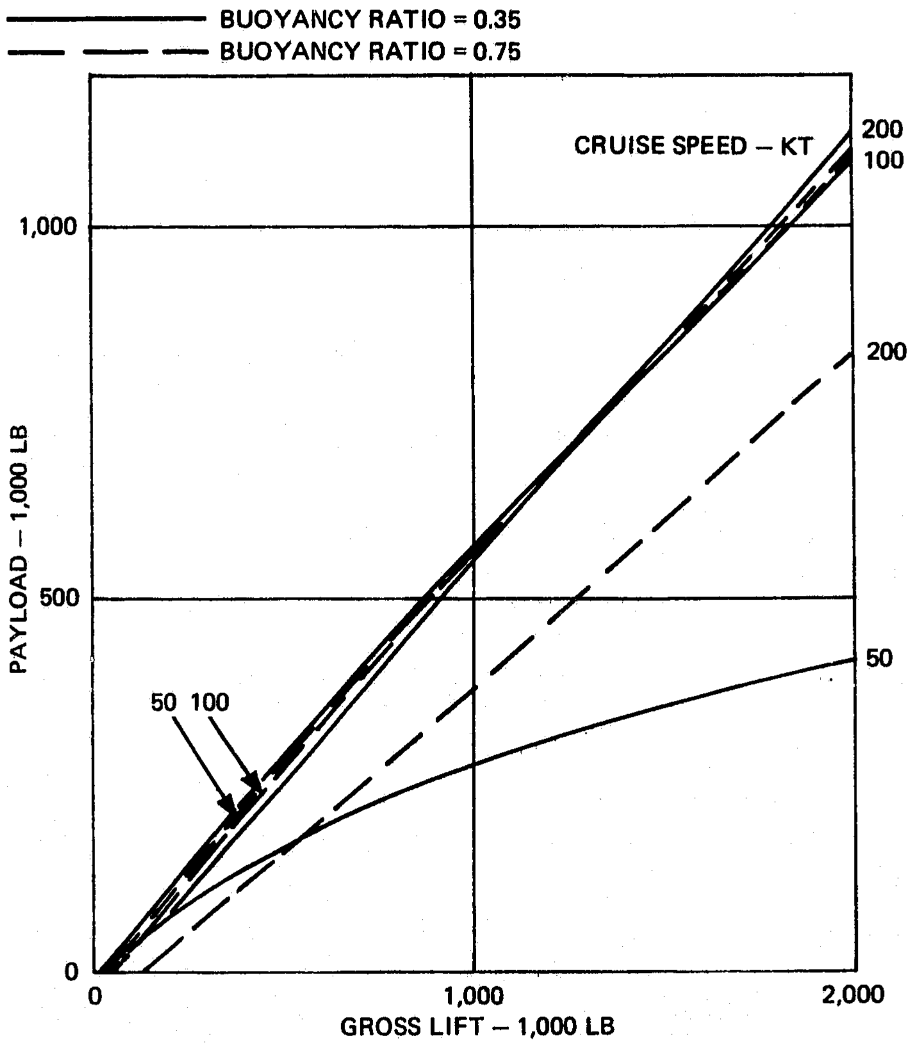
weight increases because of the higher dynamic pressure. The results are similar for the 0.75 buoyancy ratio, except the specific productivity is less because of a higher weight empty fraction. The peak specific productivity for the 0.75 buoyancy ratio occurs at approximately 130 kts (166.9 m/s). For this mission, the buoyancy ratio of 0.35 is optimum (highest specific productivity).

Figure 5-111 shows the tradeoff between payload and gross lift for buoyancy ratios of 0.75 and 0.35 and for speeds of 50, 100 and 200 kts (25.7, 51.4 and 102.9 m/s). This data shows that the ratio of payload to gross lift for a constant speed is virtually constant within the range of parameters considered. Figure 5-112 shows the weight empty and mission fuel required as a function of gross lift, buoyancy ratio and speed. From these data, the ratio of weight empty and mission fuel with gross lift is almost constant. Figure 5-113 shows the installed power and hull volume required for each gross lift for the short range mission at the specified speeds and buoyancy ratios. It should be pointed out that the data from Figures 5-111 to 5-113 were used in constructing the gross lift and specific productivity versus speed data.

Figures 5-114 through 5-119 show the same data for the 2000 N.M. (3,704 km) transcontinental mission.

Note that the shape of the curves is the same as in the short range mission, except that, for example, the minimum gross lift and productivity curves are peakier and the ratio of payload, mission fuel, and weight empty to gross weight is no longer approximately constant, but is considerably less than one and is in some cases negative. This is directly attributable to the effects of high drag (low L/D) and, therefore, high fuel consumption over a long range.

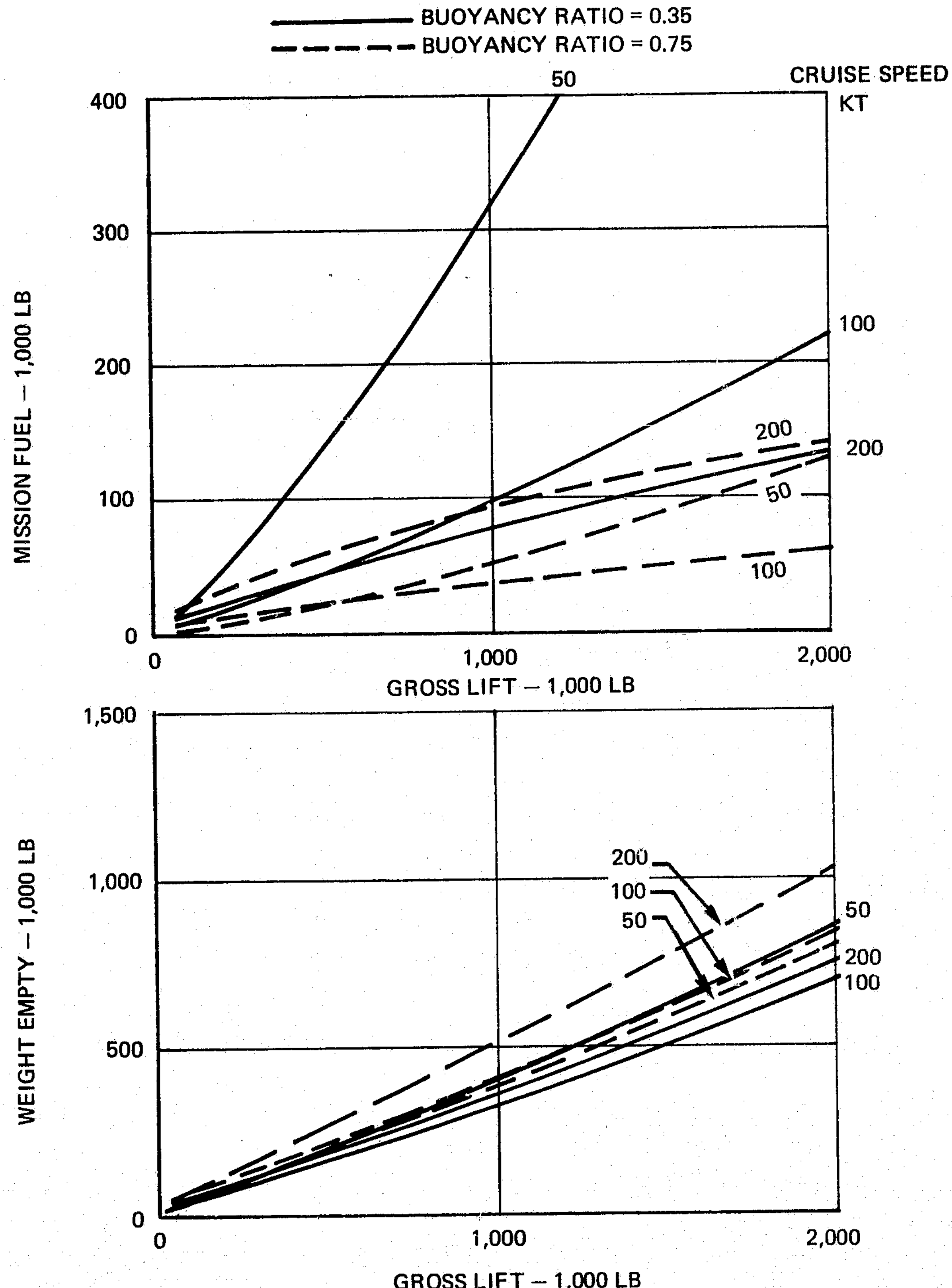
Figures 5-114 through 5-125 illustrate how this condition grows progressively worse with range - so much so that for the intercontinental mission, no real configuration exists for the buoyancy ratio = .35 Helipsoid; its payload/gross weight slope remaining



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 U.M. = 555.6 KM

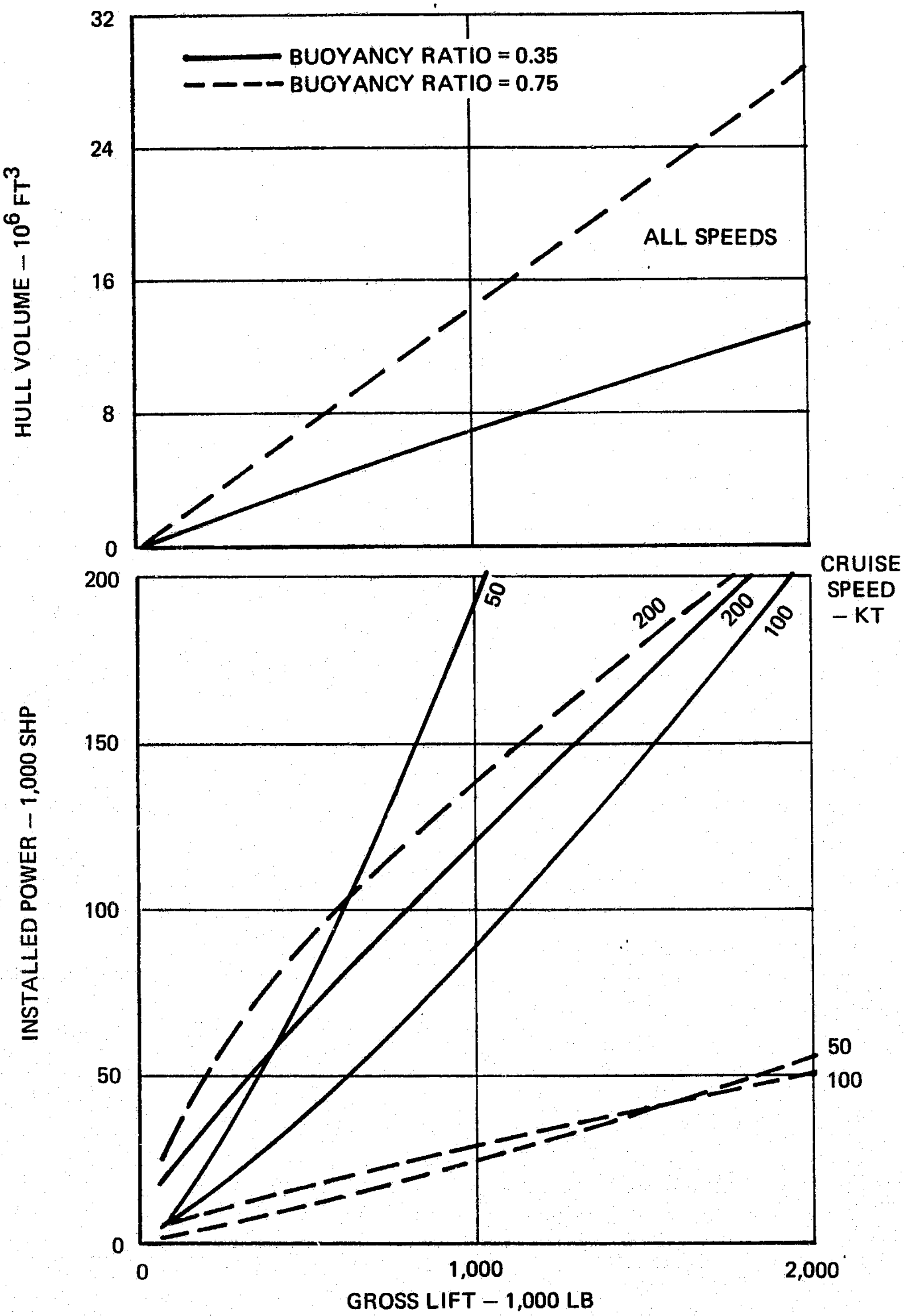
Figure 5–111. Hybrid Airship Trend Study – Helipsoid, 300 N.M. Short Range Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

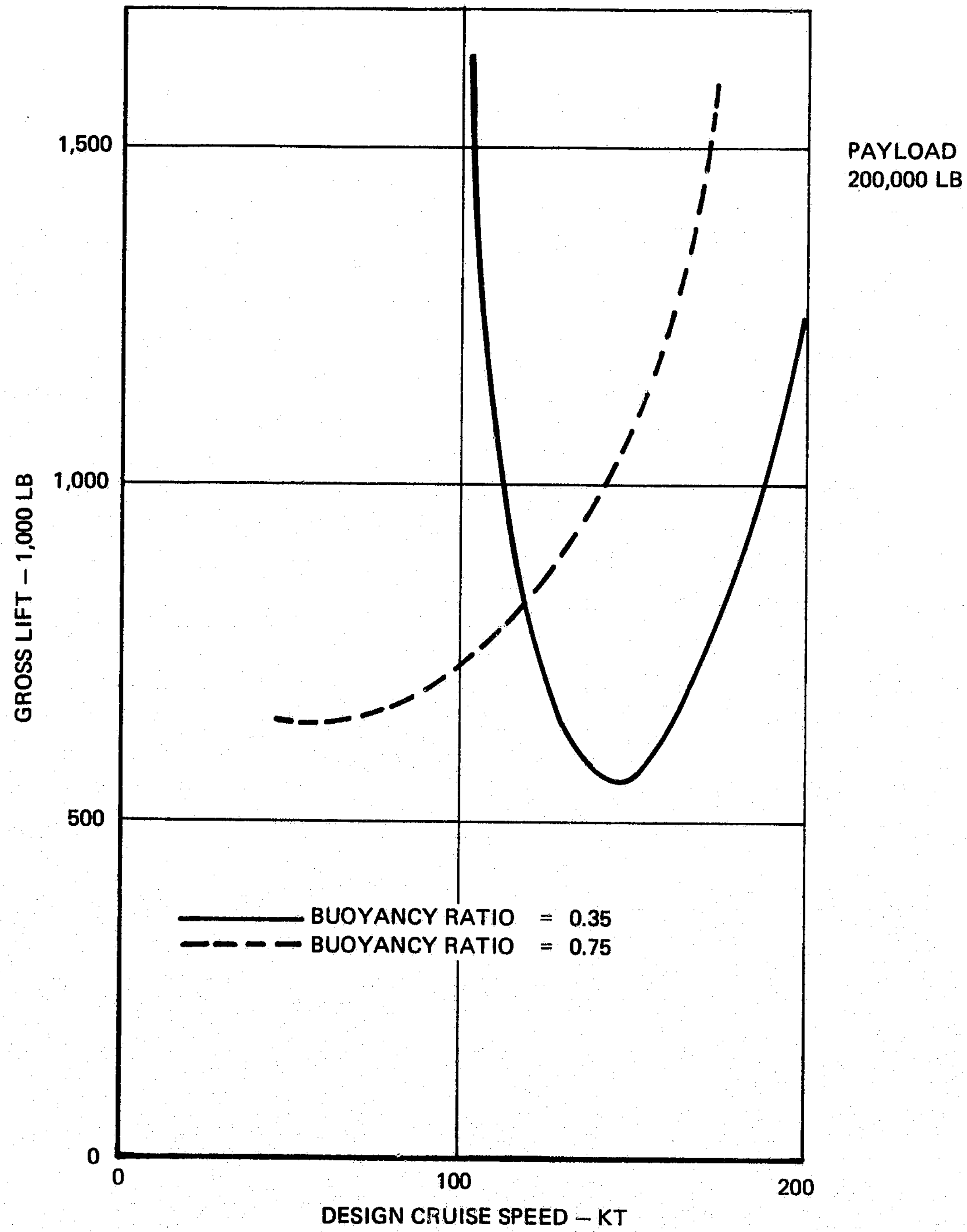
Figure 5–112. Hybrid Airship Trend Study – Helipsoid, 300 N.M. Short Range Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG   1 FT^3 = 0.0283 M^3
1 KT = 0.514 M/S   300 N.M. = 555.6 KM

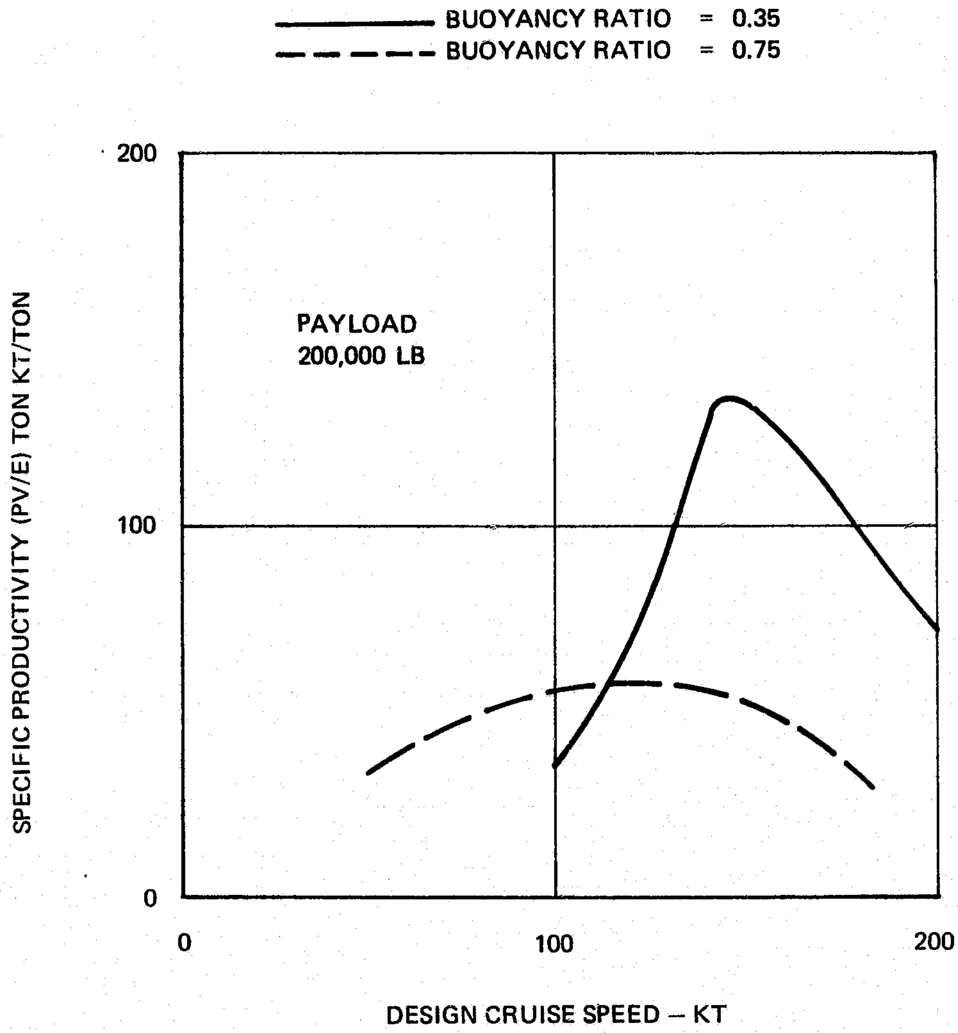
Figure 5–113. Hybrid Airship Trend Study – Helipsoid, 300 N.M. Short Range Mission – Configuration Definition



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

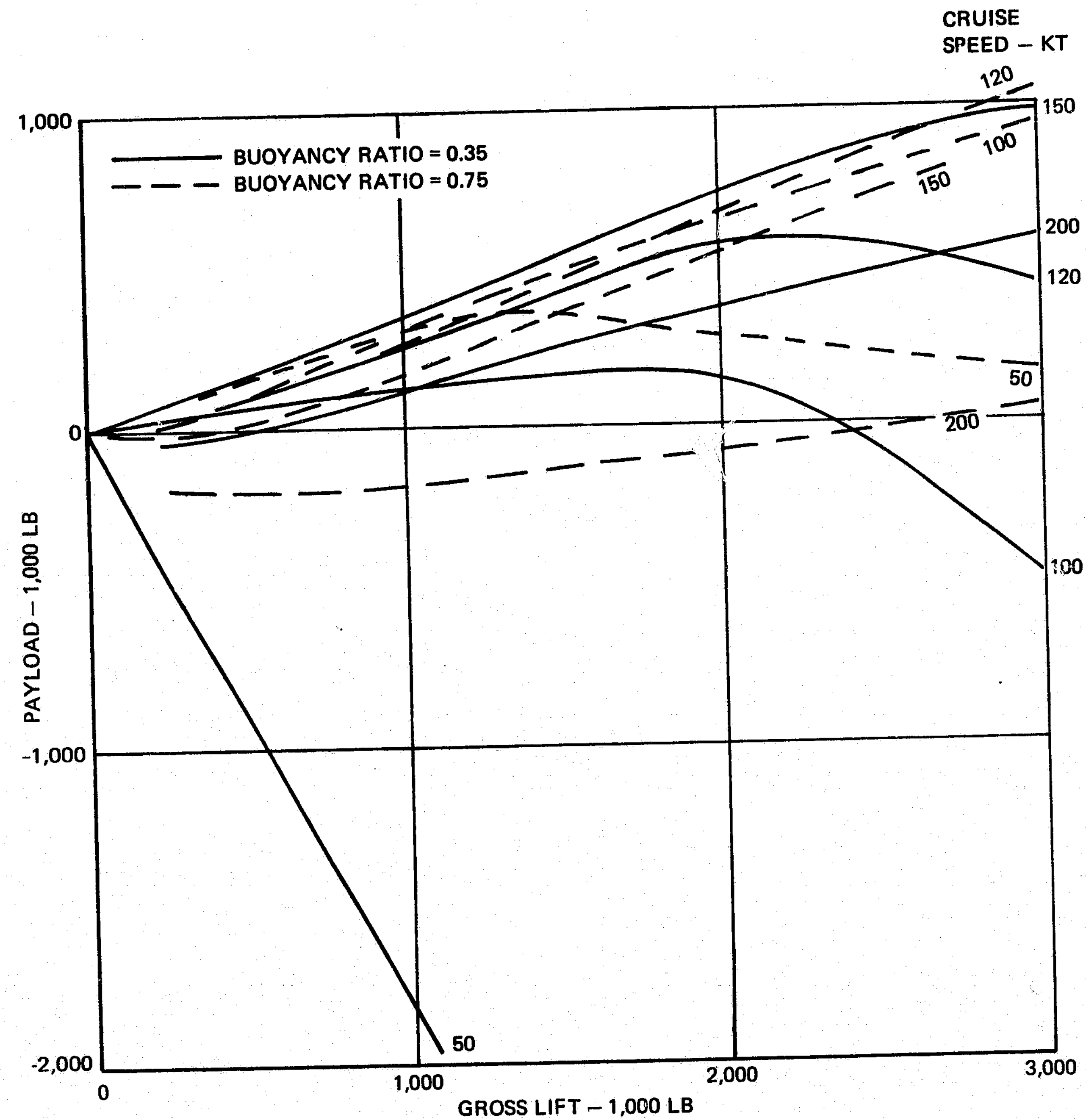
Figure 5–114. Hybrid Airship Trend Study – Helipsoid, 2,000 N.M. Transcontinental Mission – Gross Lift Requirements



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
2,000 N.M. = 3,704 KM

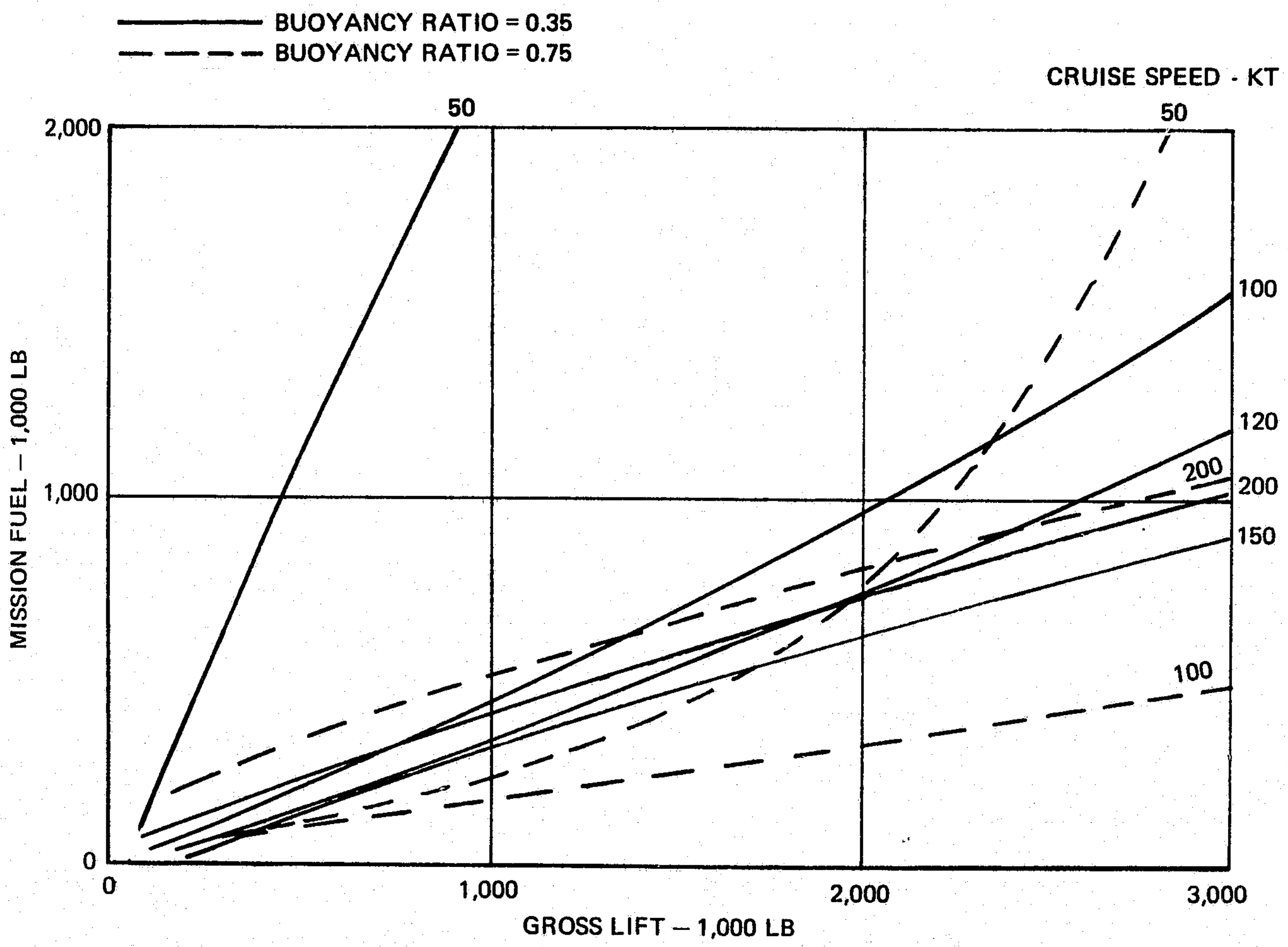
Figure 5–115. Hybrid Airship Trend Study – Helipsoid, 2,000 N.M. Transcontinental Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514
2,000 N.M. = 3,704 KM

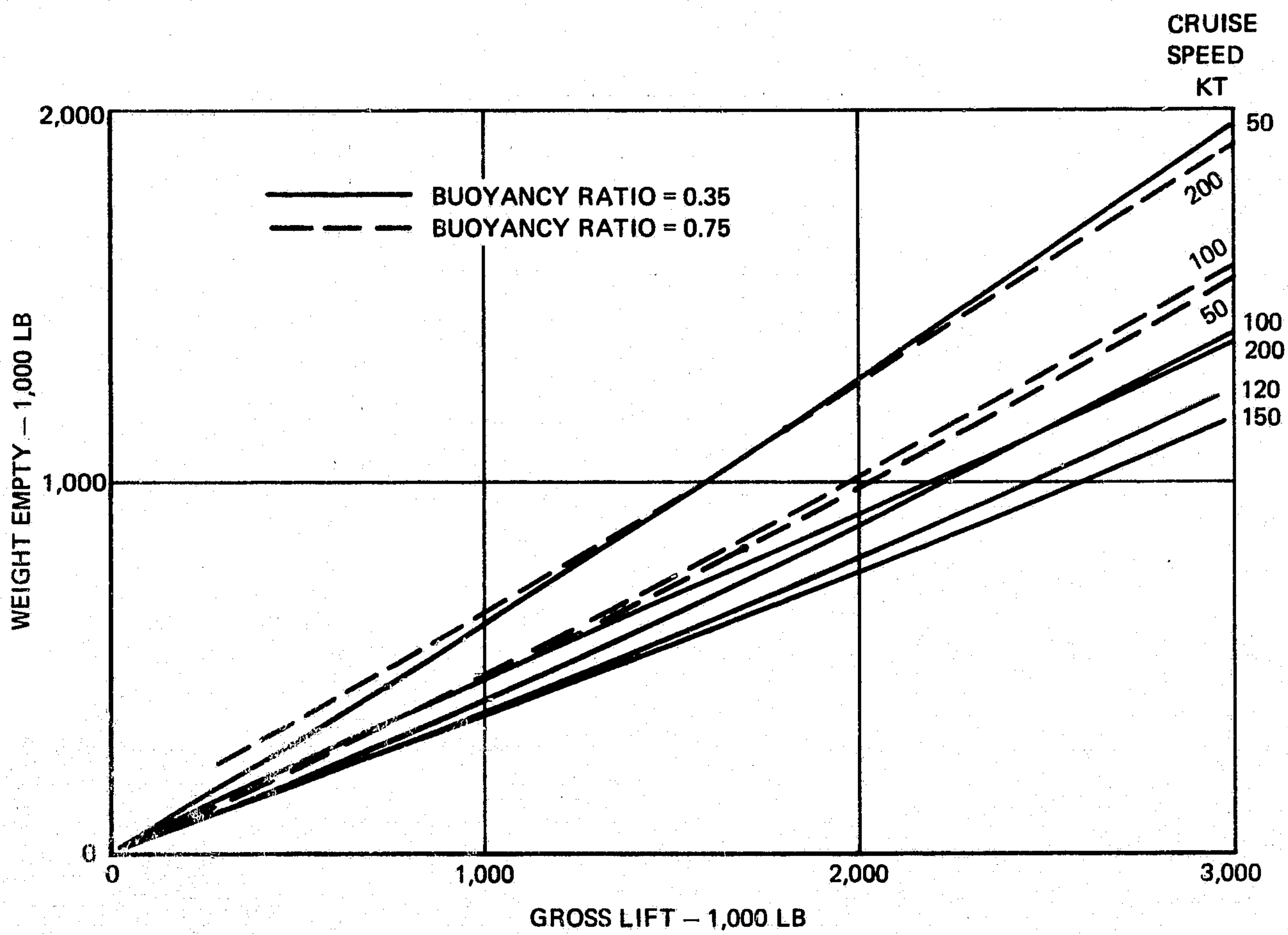
Figure 5–116. Hybrid Airship Trend Study – Helipsoid, 2,000 N.M. Transcontinental Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

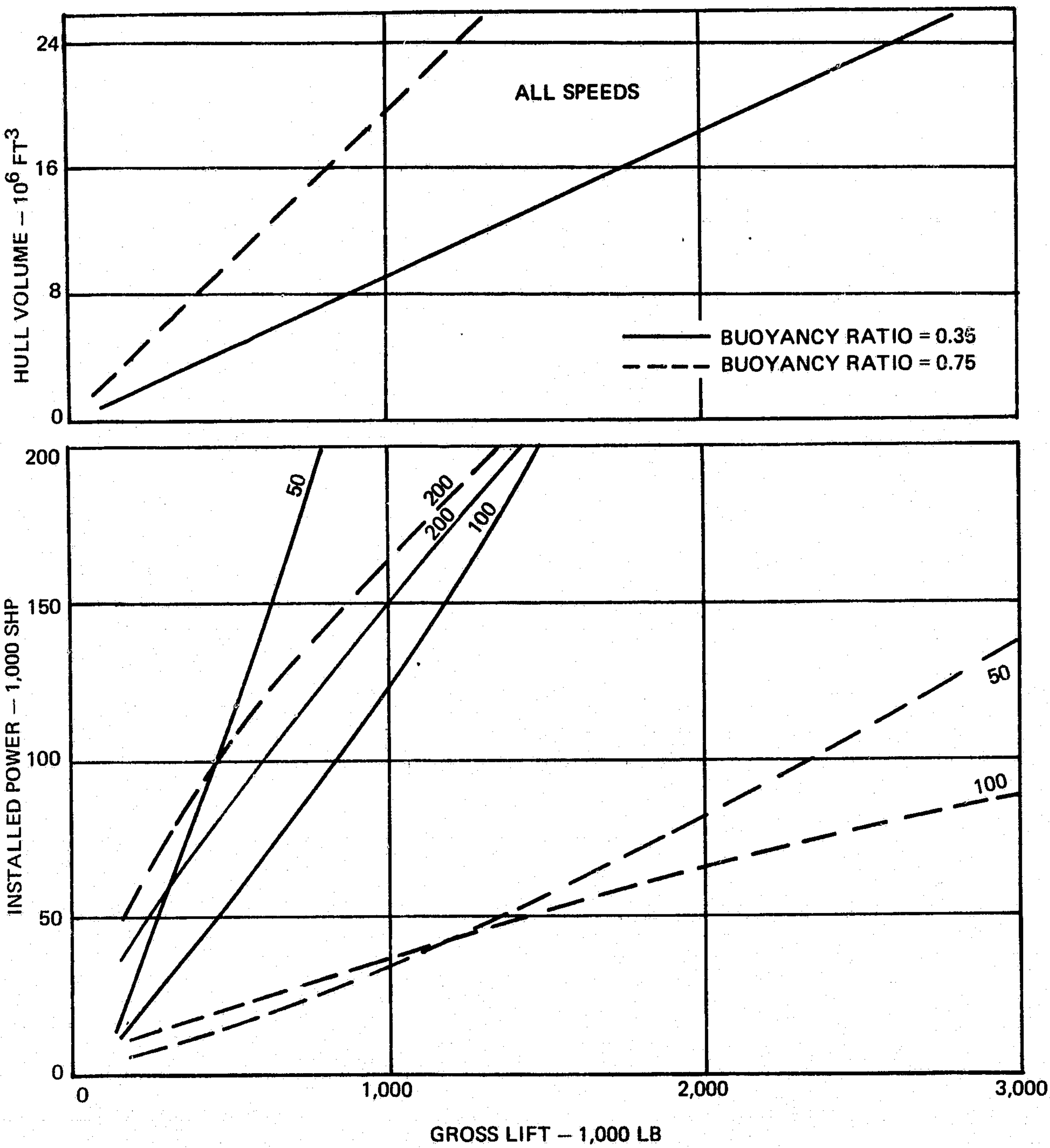
Figure 5–117. Hybrid Airship Trend Study – Helipsoid, 2,000 N.M. Transcontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

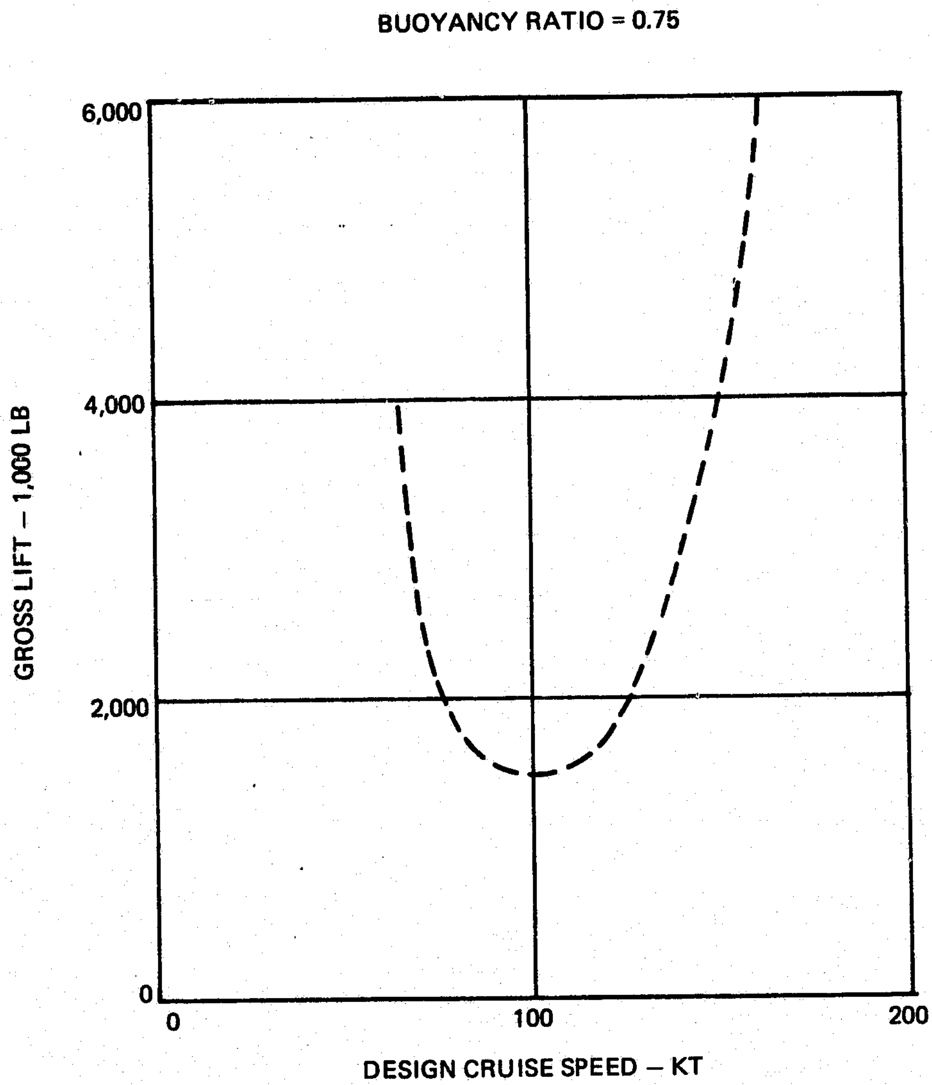
Figure 5–118. Hybrid Airship Trend Study – Helipsoid, 2,000 N.M. Transcontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
2,000 N.M. = 3,704 KM

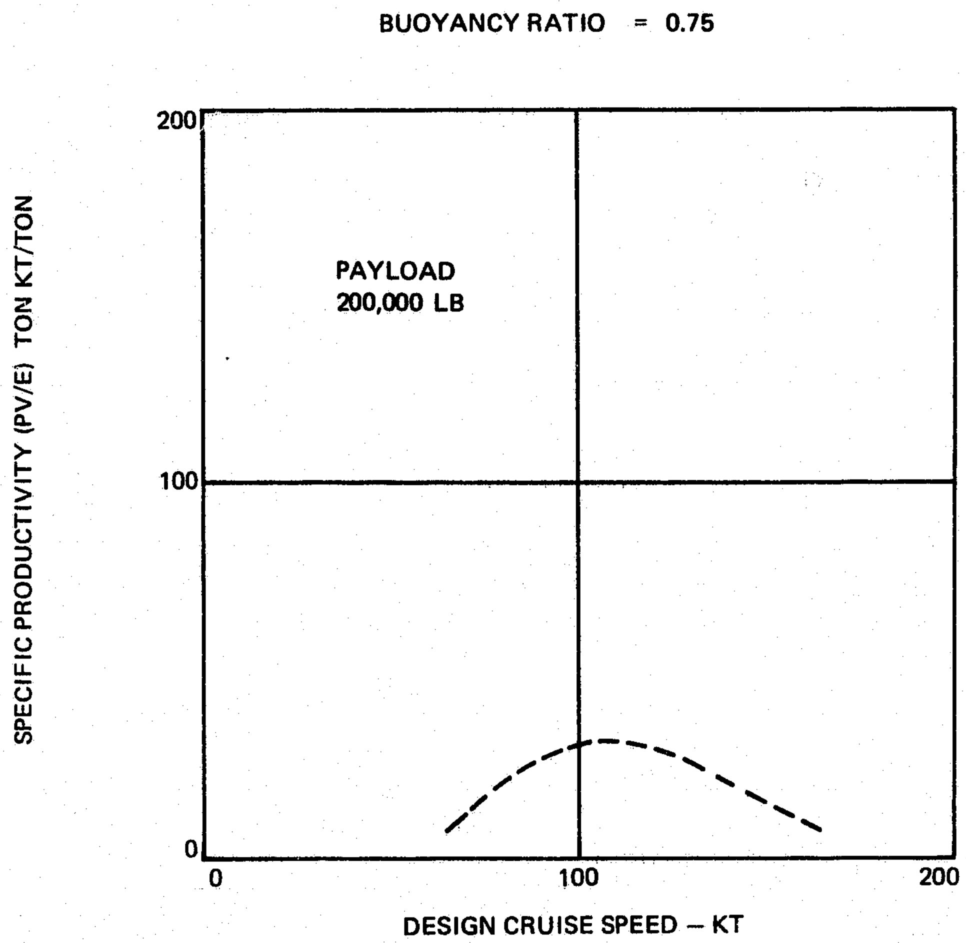
Figure 5–119. Hybrid Airship Trend Study – Helipsoid, 2,000 N.M. Transcontinental Mission – Configuration Definition



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

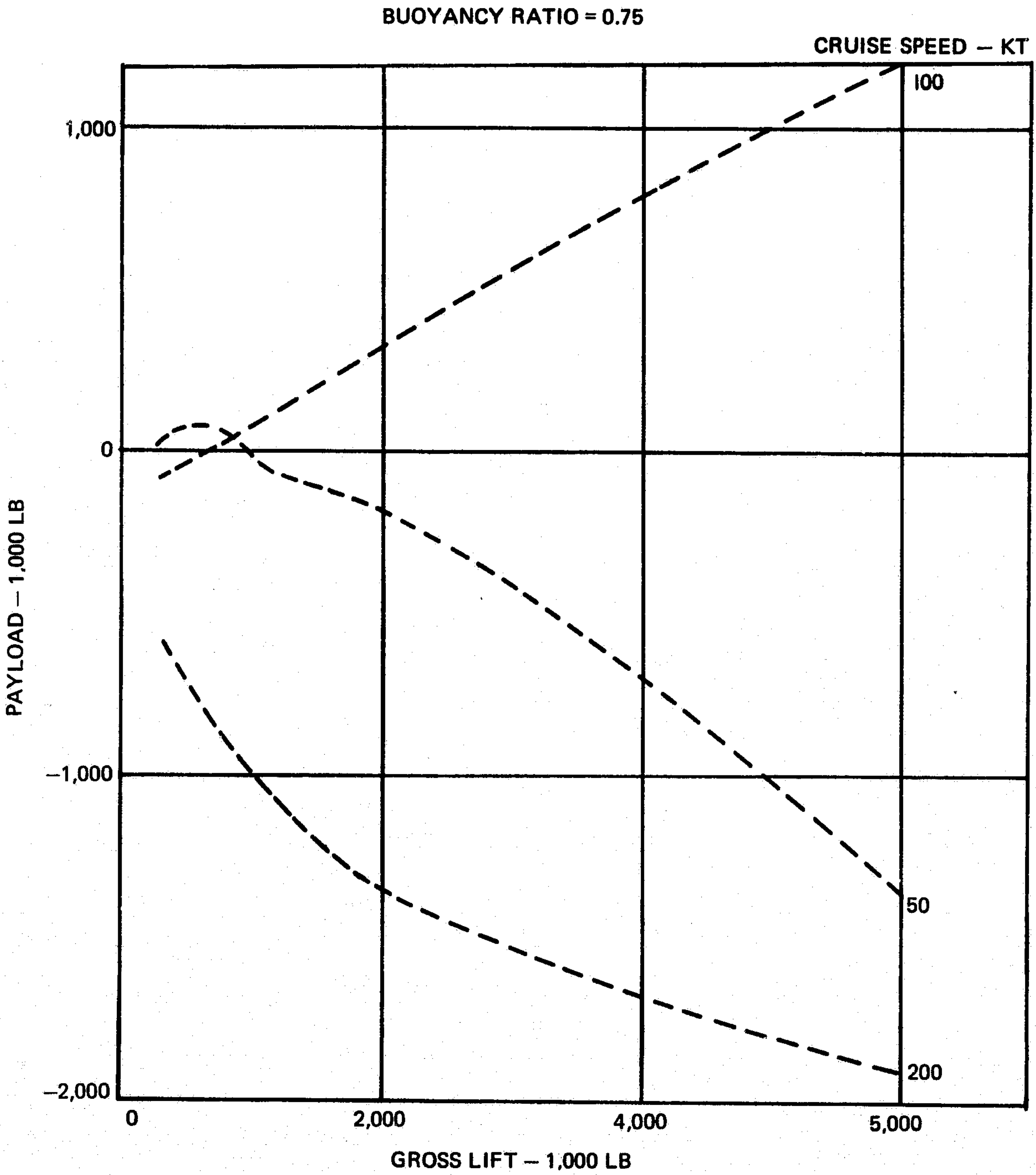
Figure 5–120.. Hybrid Airship Trend Study – Helipsoid, 5,000 N.M. Intercontinental Mission – Gross Lift Requirements



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
5,000 N.M. = 9,260 KM

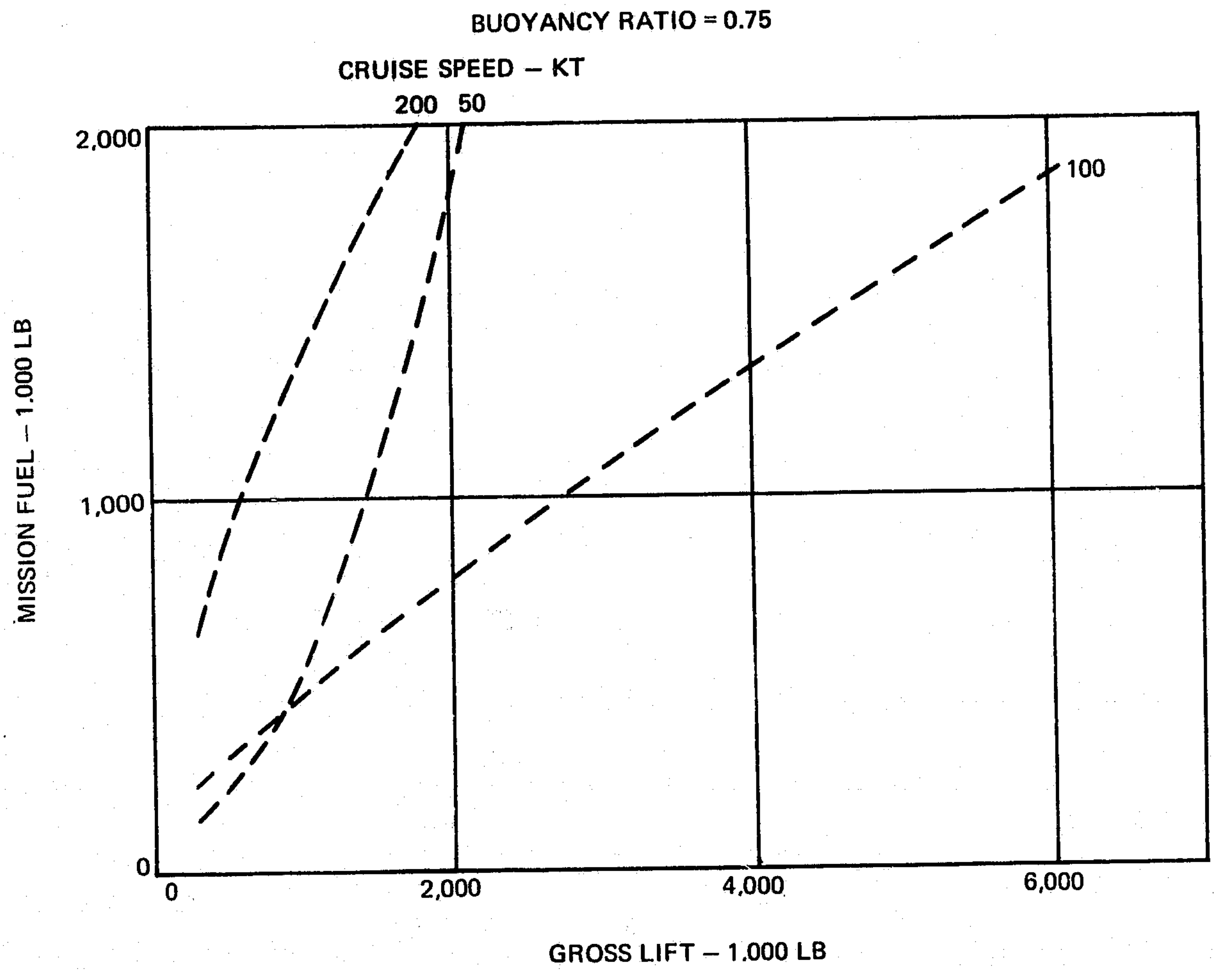
Figure 5–121. Hybrid Airship Trend Study – Helipsoid, 5,000 N.M. Intercontinental Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

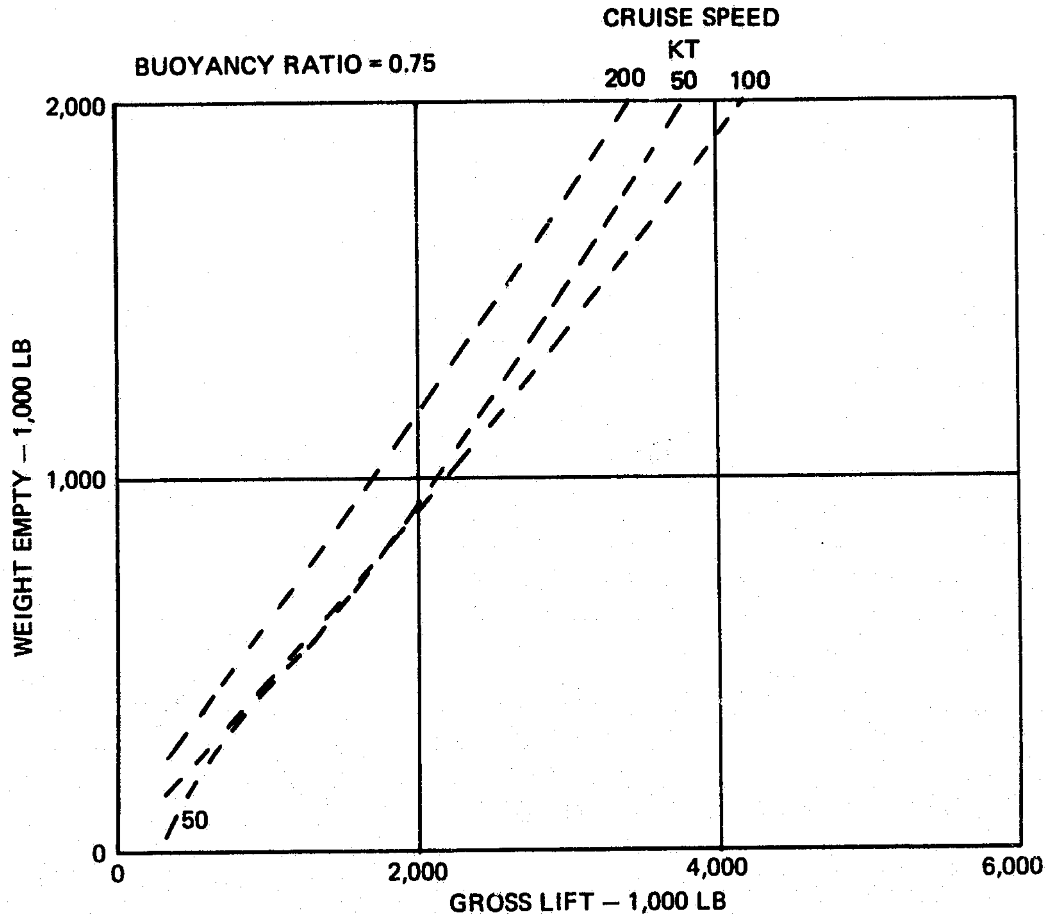
Figure 5–122. Hybrid Airship Trend Study – Helipsoid, 5,000 N.M. Intercontinental Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

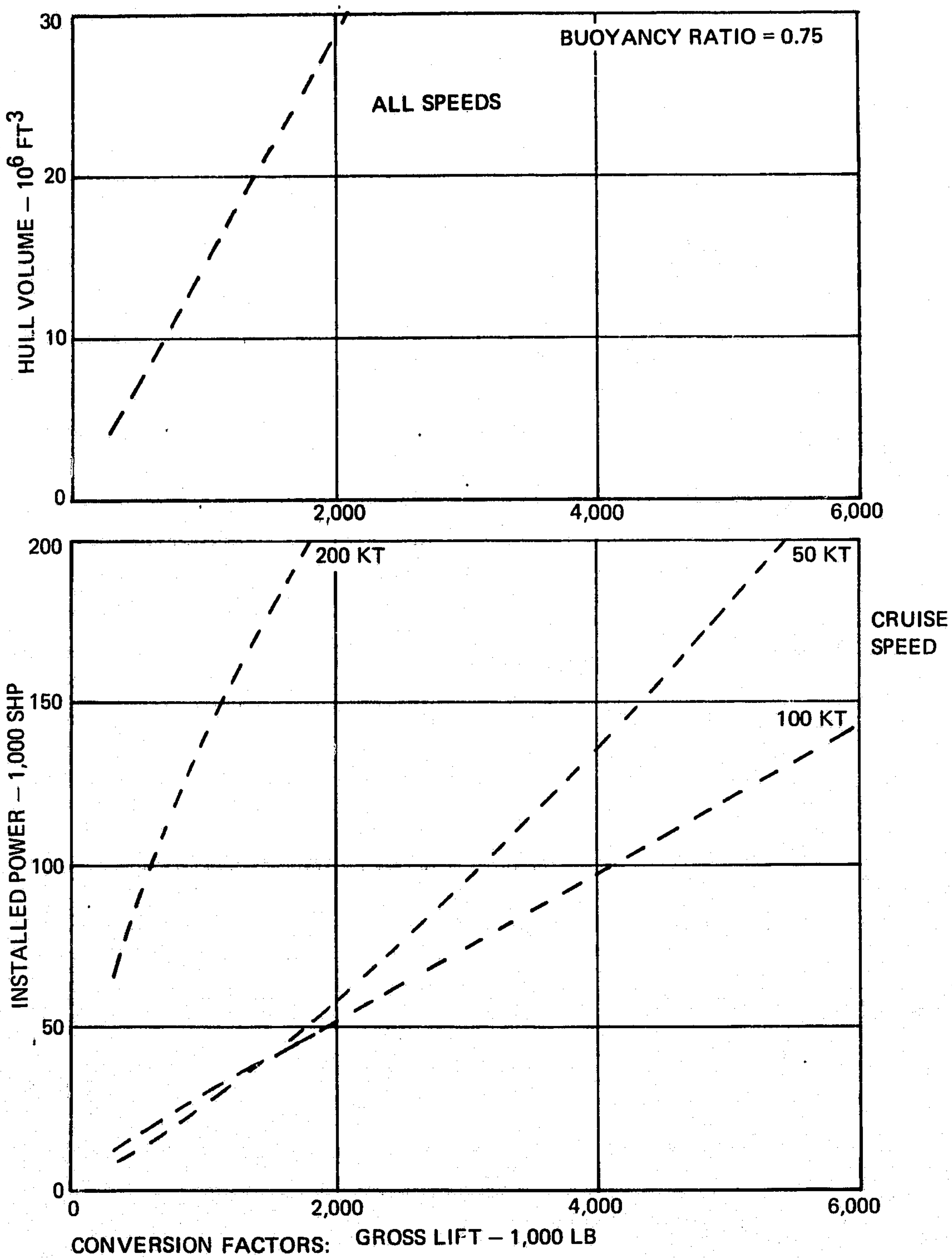
Figure 5–123. Hybrid Airship Trend Study – Helipsoid, 5,000 N.M. Intercontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

Figure 5–124. Hybrid Airship Trend Study – Helipsoid, 5,000 N.M. Intercontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
5,000 N.M. = 9,260 KM

Figure 5–125. Hybrid Airship Trend Study – Helipsoid, 5,000 N.M. Intercontinental Mission – Configuration Definition

negative at all speeds and gross lifts investigated in this study.

5.4.3.6 Helistat Parametric Results

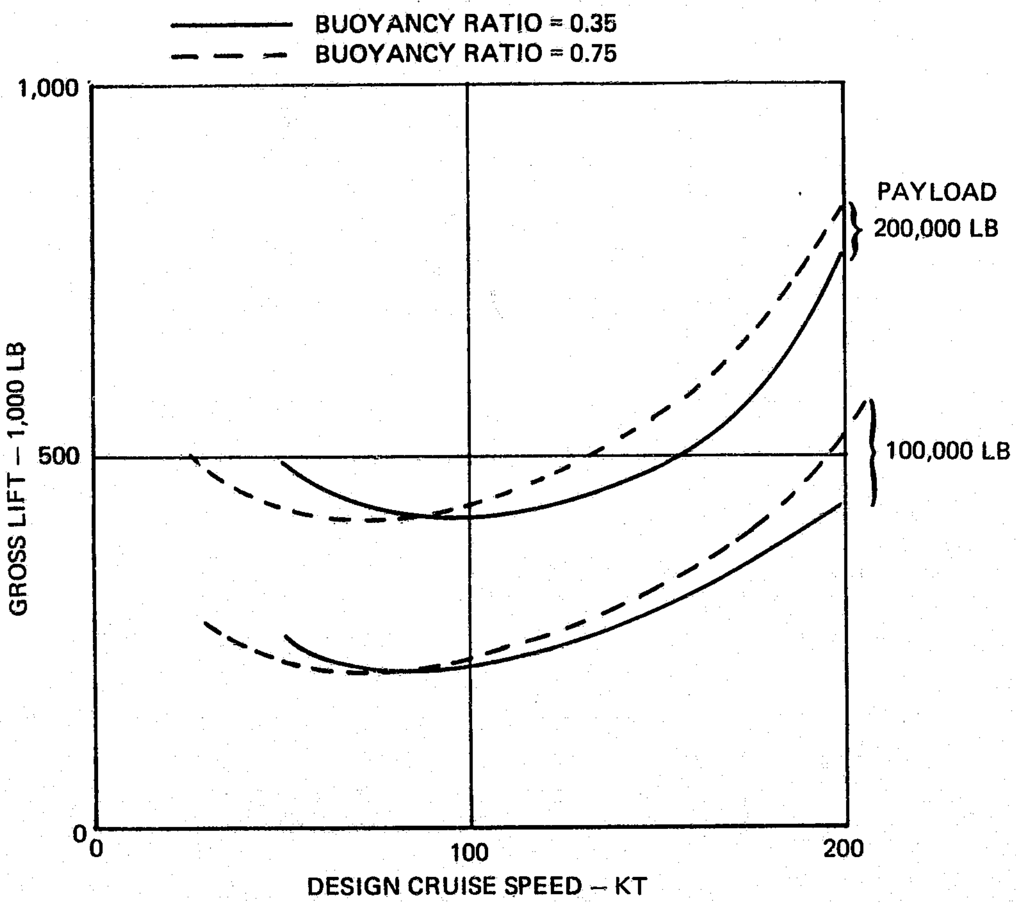
The Helistat configuration consists of a conventional rigid airship hull fitted with four helicopter rotors that provide vertical lift and forward propulsion. The rotors were sized to provide a disc loading of 11.0 lb/ft^2 (54 kg/m) and the engine driving them were sized to allow the vehicle to achieve the design cruise speed at specified weights and altitude.

The performance of the Helistat in the 300 N.M. (556 Km) (short range) mission is presented in Figures 5-126 through 5-130.

Figure 5-126 shows the gross lift versus design cruise speed for payloads of 100,000 and 200,000 lb. (45,400 and 90,800 kg) at buoyancy ratios of 0.35 and 0.75. As is to be expected, the heavier payload always requires a larger gross lift.

The effect of buoyancy ratio on minimum gross lift is very small from the data presented. This is because the values chosen lie on either side of the optimum buoyancy ratio for the mission.

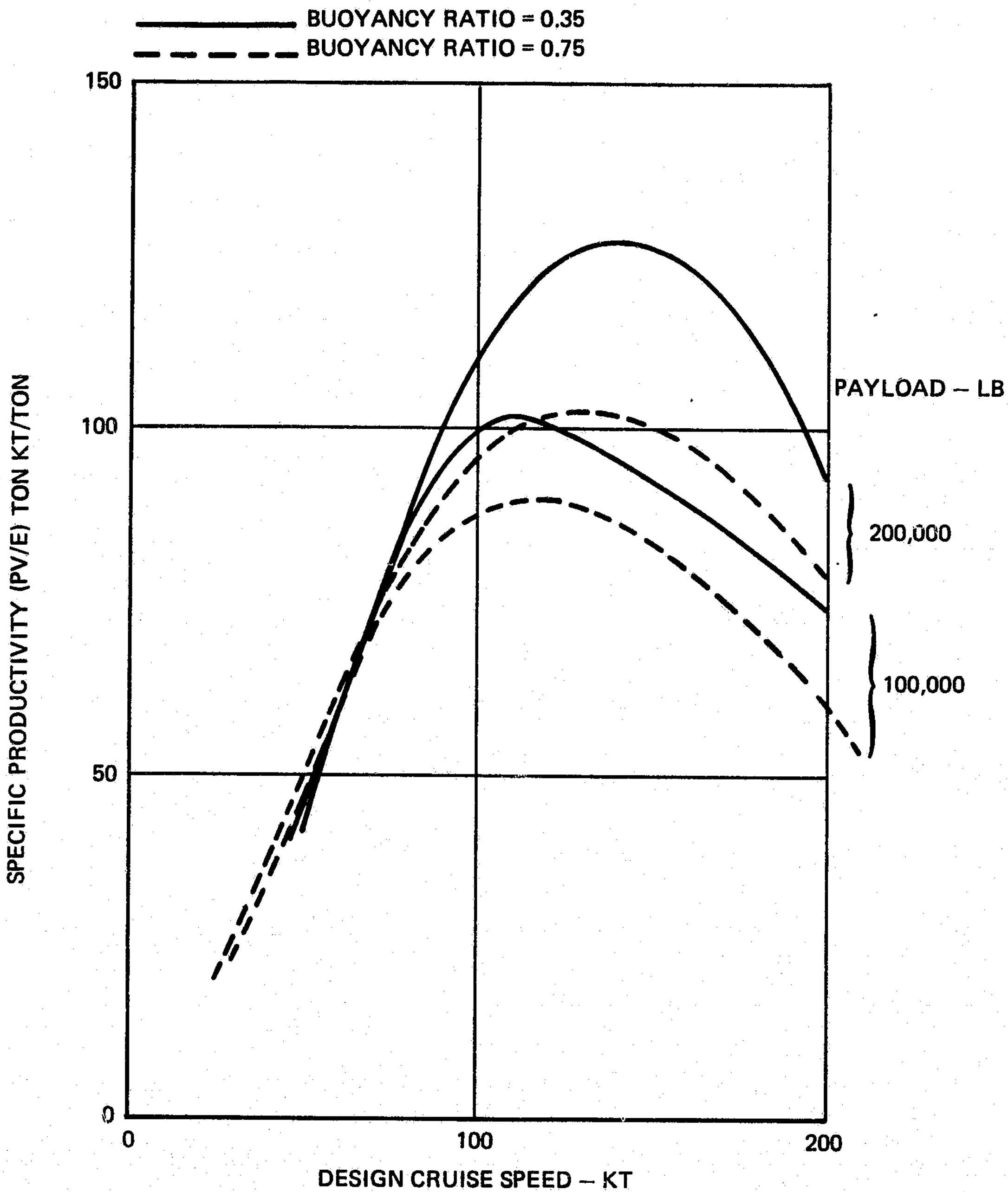
The variation of gross lift required with speed has roughly the same shape as the typical helicopter power required curve and, indeed, the airship could be considered to be nothing more than a four rotor helicopter with a large fuselage. At low speed, the rotor induced power is predominant but reduces rapidly as the speed increases. At higher speeds, the profile power increases rapidly. The higher power levels associated with the low and high speeds result in larger fuel consumption rates than at the lower power levels. The increased fuel required causes the gross lift requirement to be increased (by increasing the airship size) which, in turn, results in higher drag levels (which then increase the fuel requirements) and higher weight.



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

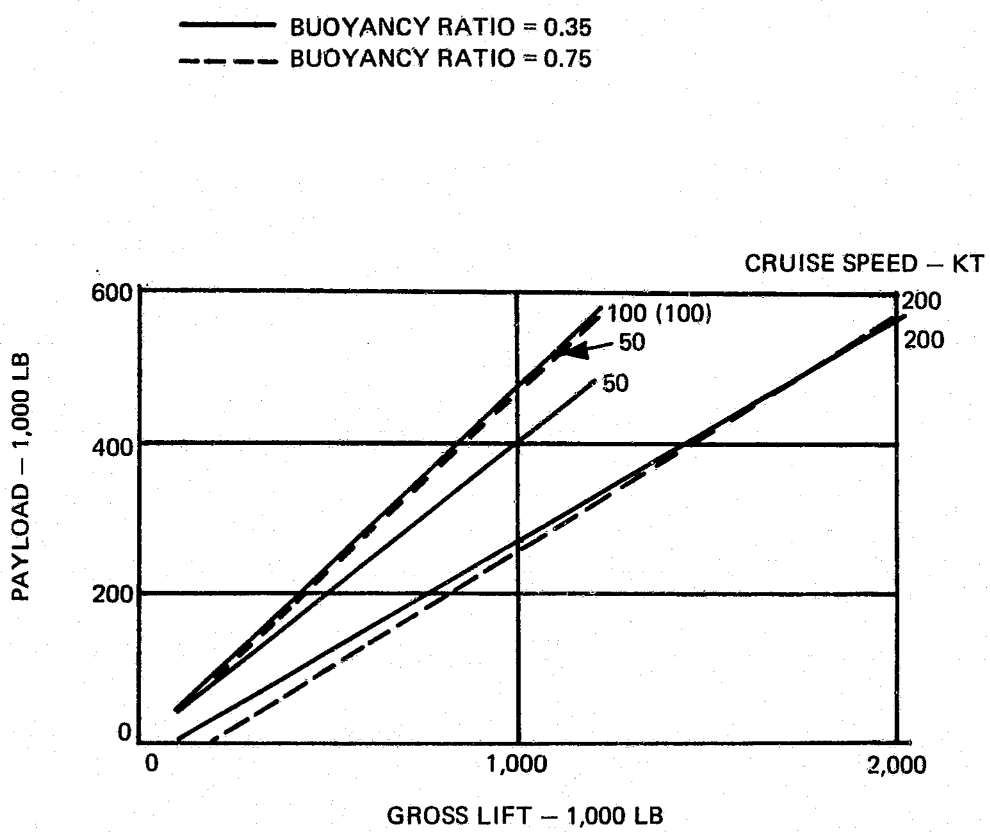
Figure 5–126. Hybrid Airship Trend Study – Heli-Stat, 300 N.M. Short Range Mission – Gross Lift Requirement



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
300 N.M. = 555.6 KM

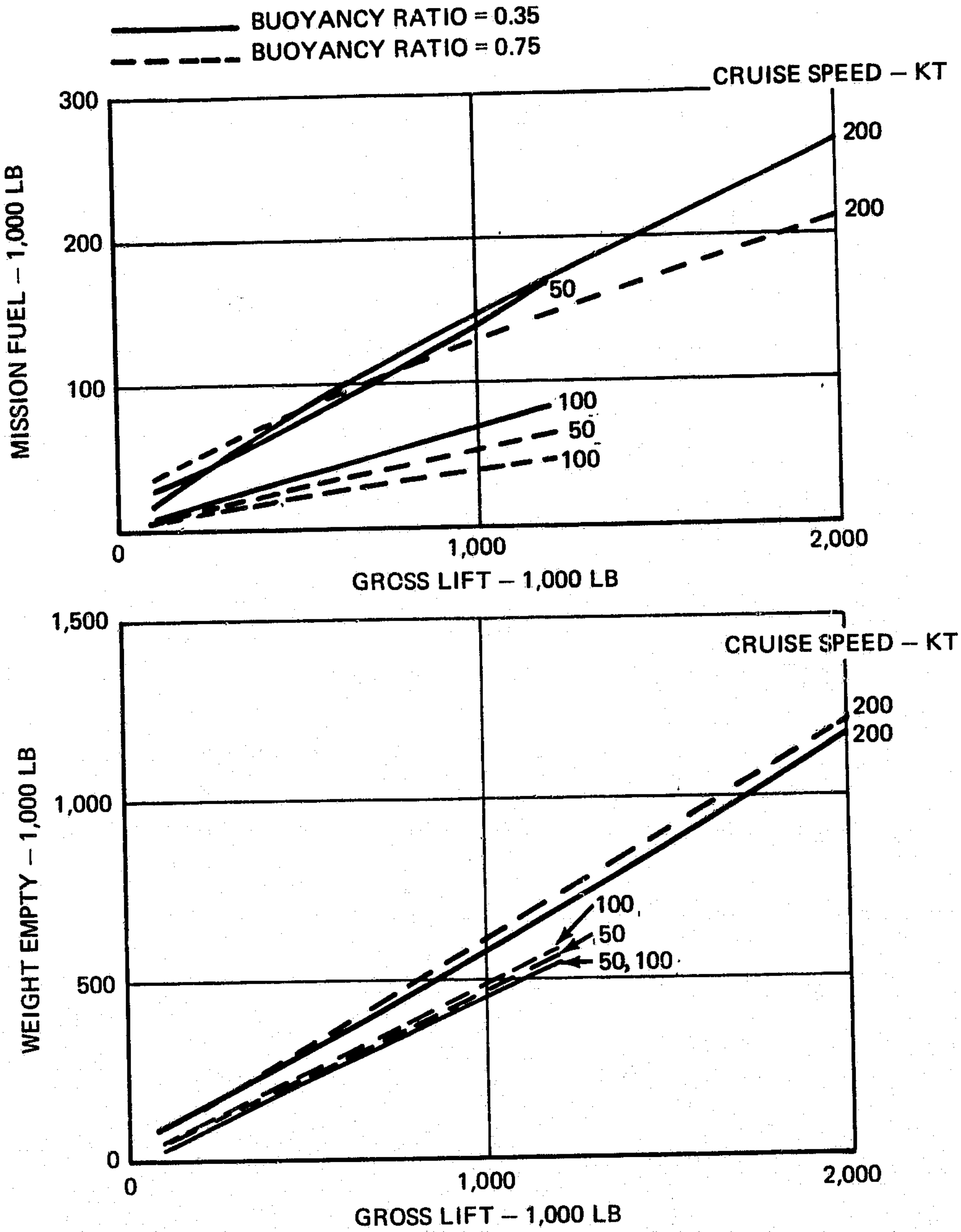
Figure 5–127. Hybrid Airship Trend Study – Heli-Stat, 300 N.M. Short Range Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6 KM

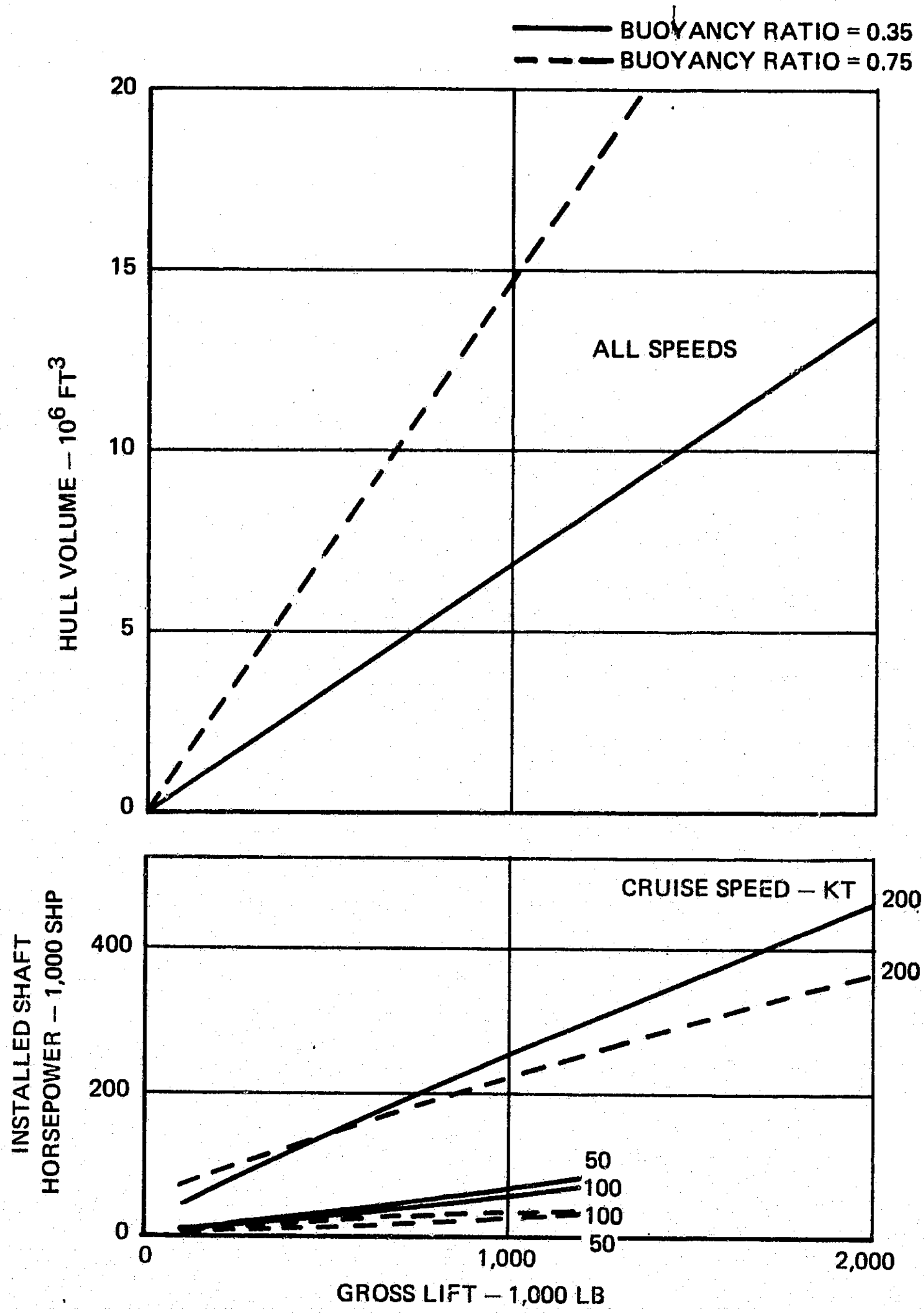
Figure 5–128. Hybrid Airship Trend Study – Heli-Stat, 300 N.M. Short Range Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
300 N.M. = 555.6

Figure 5–129. Hybrid Airship Trend Study – Heli-Stat, 300 N.M. Short Range Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
300 N.M. = 555.6 KM

Figure 5–130. Hybrid Airship Trend Study – Heli-Stat, 300 N.M. Short Range Mission – Configuration Definition

Figure 5-127 shows the specific productivity for the Helistat configuration flying the short range mission. In this mission, the lower buoyancy ratio has the higher productivity over most of the speed range studied.

At the higher buoyancy ratio, a larger gas volume is required to produce the same lift. This larger size results in a higher drag level, increased structure weight and, consequently, a higher gross lift. At the same time, the higher drag leads to higher mission fuel, thus producing more growth of the vehicle.

Figure 5-128 shows the payload capability of the Helistat as a function of gross lift at design cruise speeds of 50, 100 and 200 kts (25.7, 51.4 and 102.9 m/s). The payload is seen to be roughly proportional to the gross lift at any given speed. This figure was the source of the data shown in Figure 5-126. Figure 5-129 shows the weight empty and mission fuel for the short range mission as functions of gross lift for the design cruise speeds of 50, 100 and 200 kts (25.7, 51.4 and 102.9 m/s). These curve all exhibit the same type of trend with gross weight as the payload at a given speed.

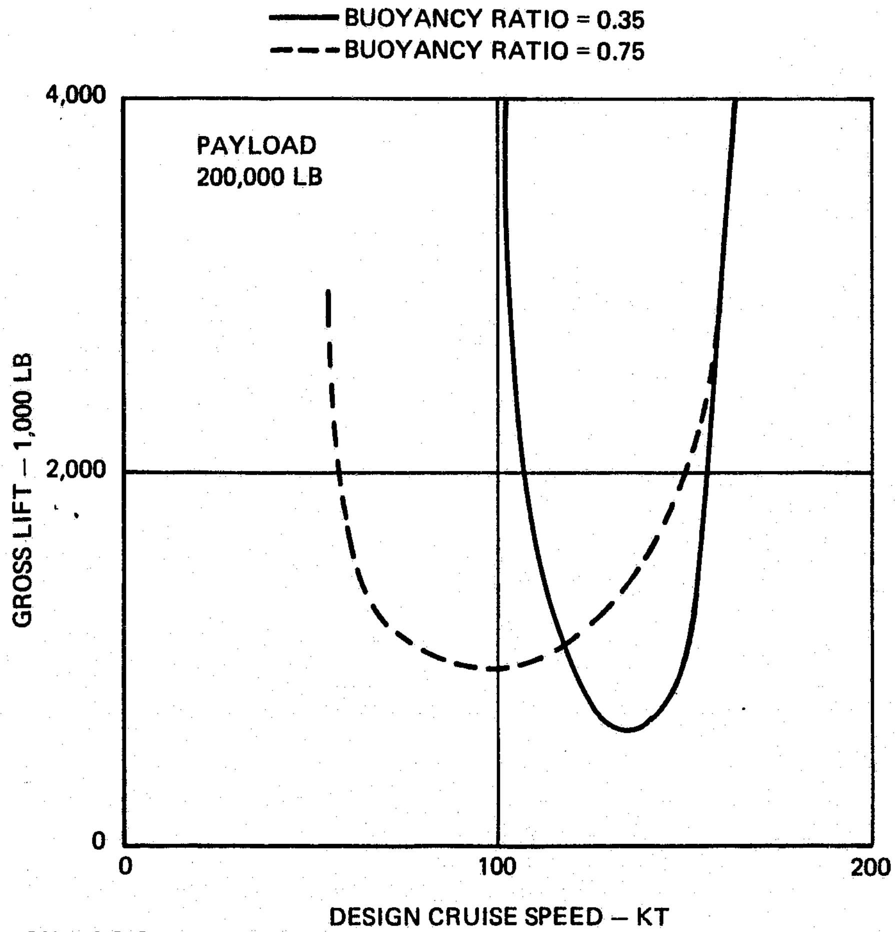
The curves in Figure 5-130 show the variation of hull volume with gross lift and the variation of installed shaft horsepower as a function of gross lift for the three design speeds. The latter durve indicates that, at the maximum cruise speed considered, 200 kts (102.9 m/s) the lower buoyancy ratio airship requires a higher installed power at given gross lift. This is reflected in Figure 5-130 which shows that the higher power level corresponds with a higher fuel requirement, again at specified gross weight. The hull volume at the given gross lift is much lower for the lower buoyancy ratio so the hull parasite drag must also be smaller. This consideration indicates a lower power and fuel requirement. However, the lower buoyancy ratio airship requires a higher lift from the helicopter rotors. It is this requirement that results in the higher rotor diameter and consequent larger engine size.

Figures 5-131 through 5-135 show a similar set of data for the 2000 N.M. (3,704 Km), high altitude transcontinental mission. The corresponding data for the Helistat flying the intercontinental (5000 (N.M., 9,260 Km) mission are given in Figures 5-136 through 5-140.

Comparison of Figures 5-126, 5-131 and 5-136 show that the minimum gross lift required for a given payload increases with range. That the amount of fuel required for the longer missions is a prime factor in the growth of gross lift with range can be seen by comparing the mission fuel curves, Figures 5-129, 5-134 and 5-139 at a given speed and gross weight.

A comparison of Figures 5-127, 5-132 and 5-137 shows the effect of range on the specific productivity of the Helistat. The value of maximum specific productivity is seen to decrease rapidly as range is increased from 300 to 2000 N.M. (556 to 3,704 Km). The rate of decrease gets smaller as the range is increased further. Another noteworthy fact is that as the range is increased, the specific productivity becomes extremely sensitive to cruise speed, small deviations from the optimum causes large reductions in productivity. These facts all stem from the increased fuel requirement of the long range missions.

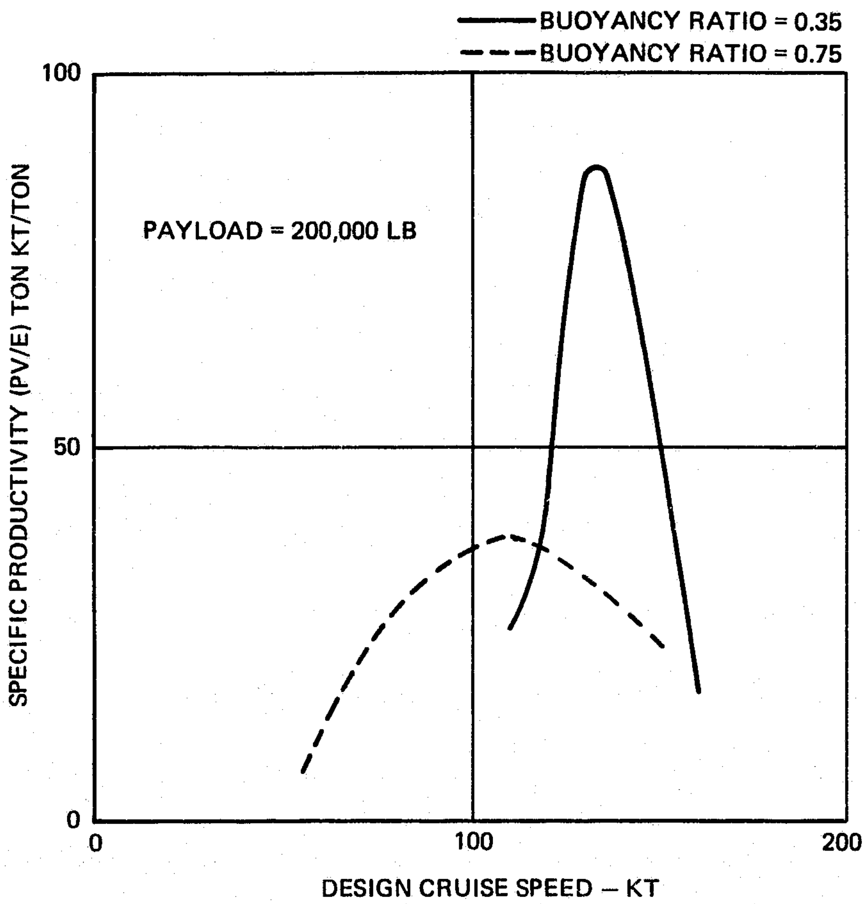
In the case of the 5000 N.M. (9,260 Km) for the range of speeds and gross lifts considered, 50 to 200 kts. (25.7 to 102.9 m/s) and 2,000,000 to 20,000,000 lb. (907,200 to 9,072,000 kg), respectively, the Helistate of 0.35 buoyance ratio was incapable of performing the mission with a positive payload. Thus, no solid lines appear on the graphs of gross lift requirement, productivity or payload capability, Figure 5-134, 5-137 and 5-138, respectively. The data of Figure 5-139 can be used to deduce that for these cases a negative payload would result by subtracting the weight empty and fuel required from the gross lift for any given condition.



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

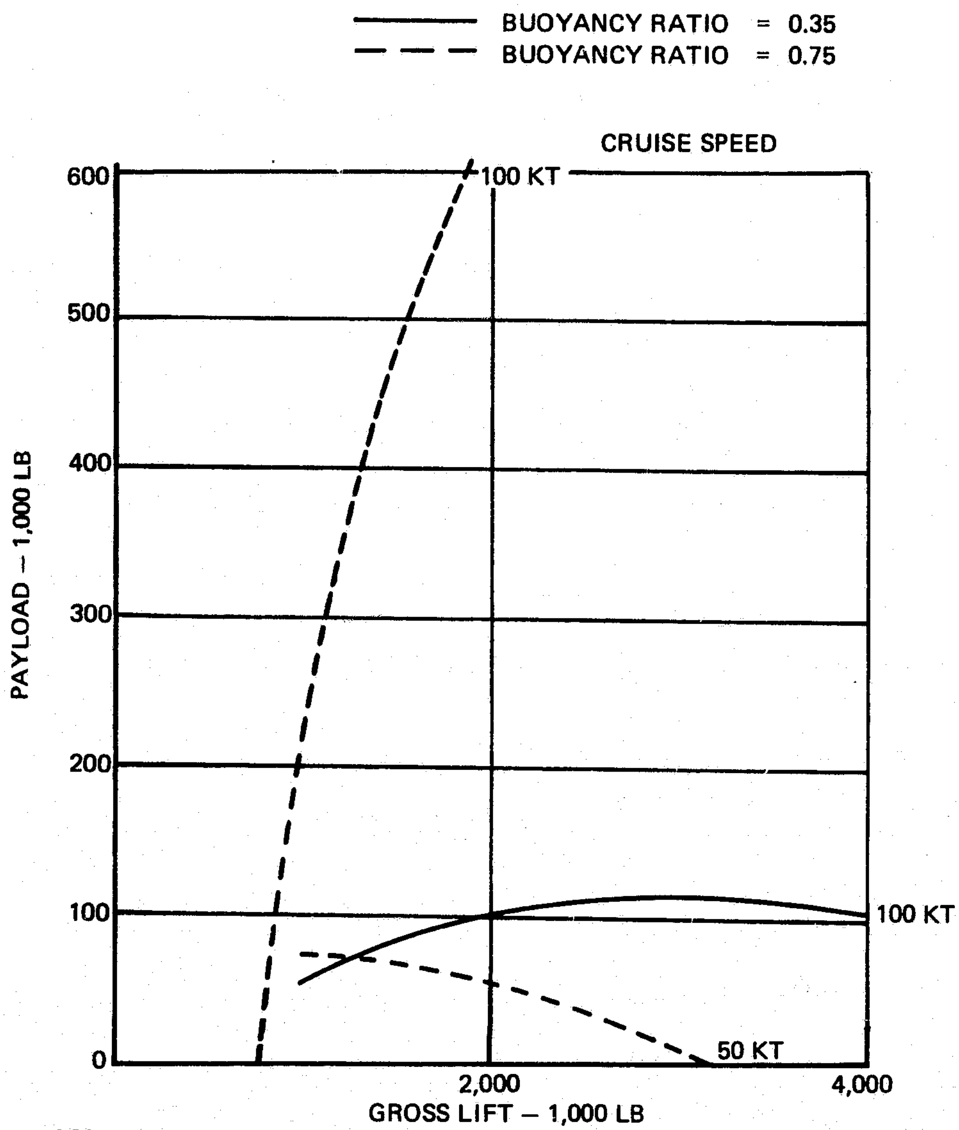
Figure 5–131. Hybrid Airship Trend Study – Heli-Stat, 2,000 N.M. Transcontinental Mission – Gross Lift Requirement



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
2,000 N.M. = 3,704 KM

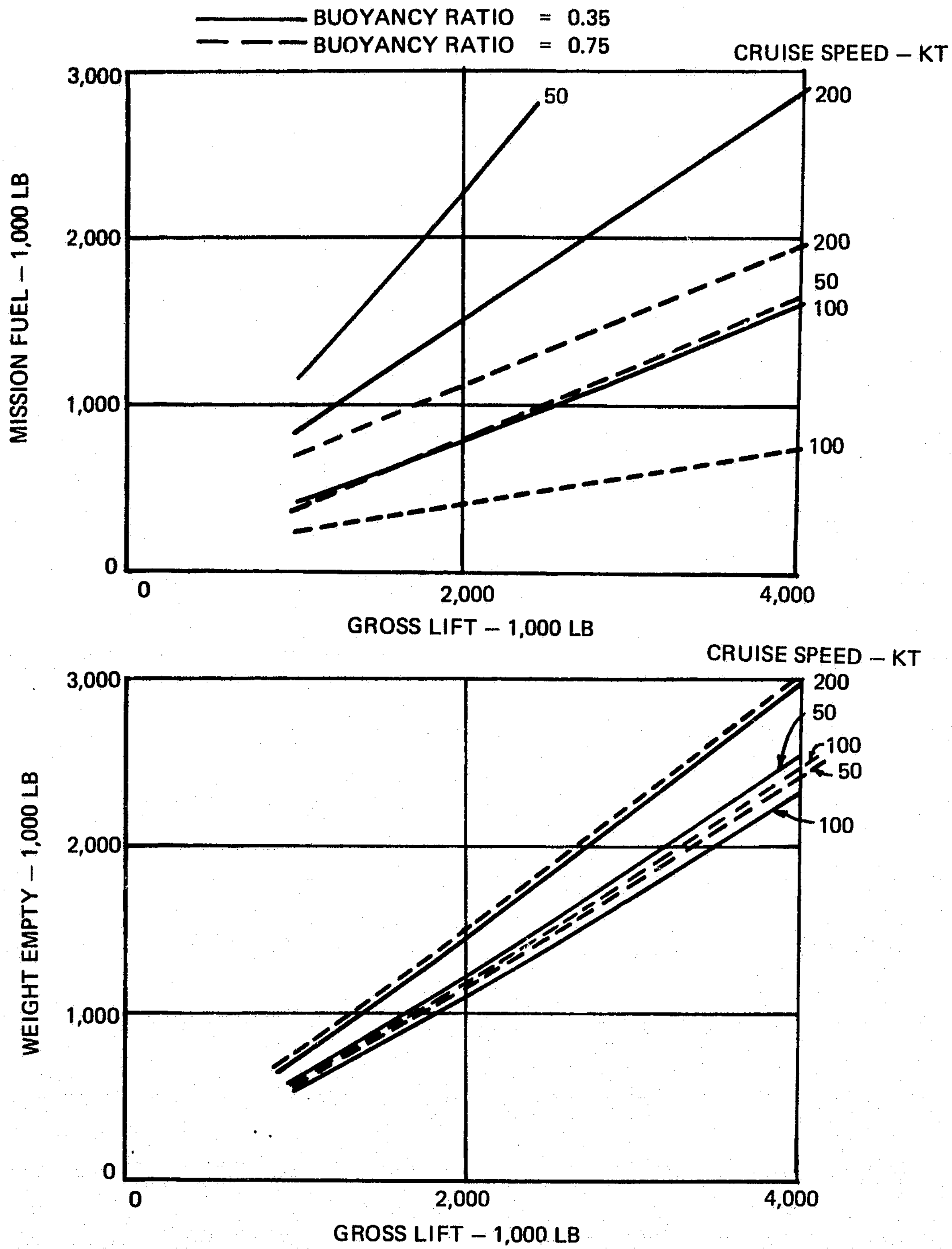
Figure 5–132. Hybrid Airship Trend Study – Heli-Stat, 2,000 N.M. Transcontinental Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

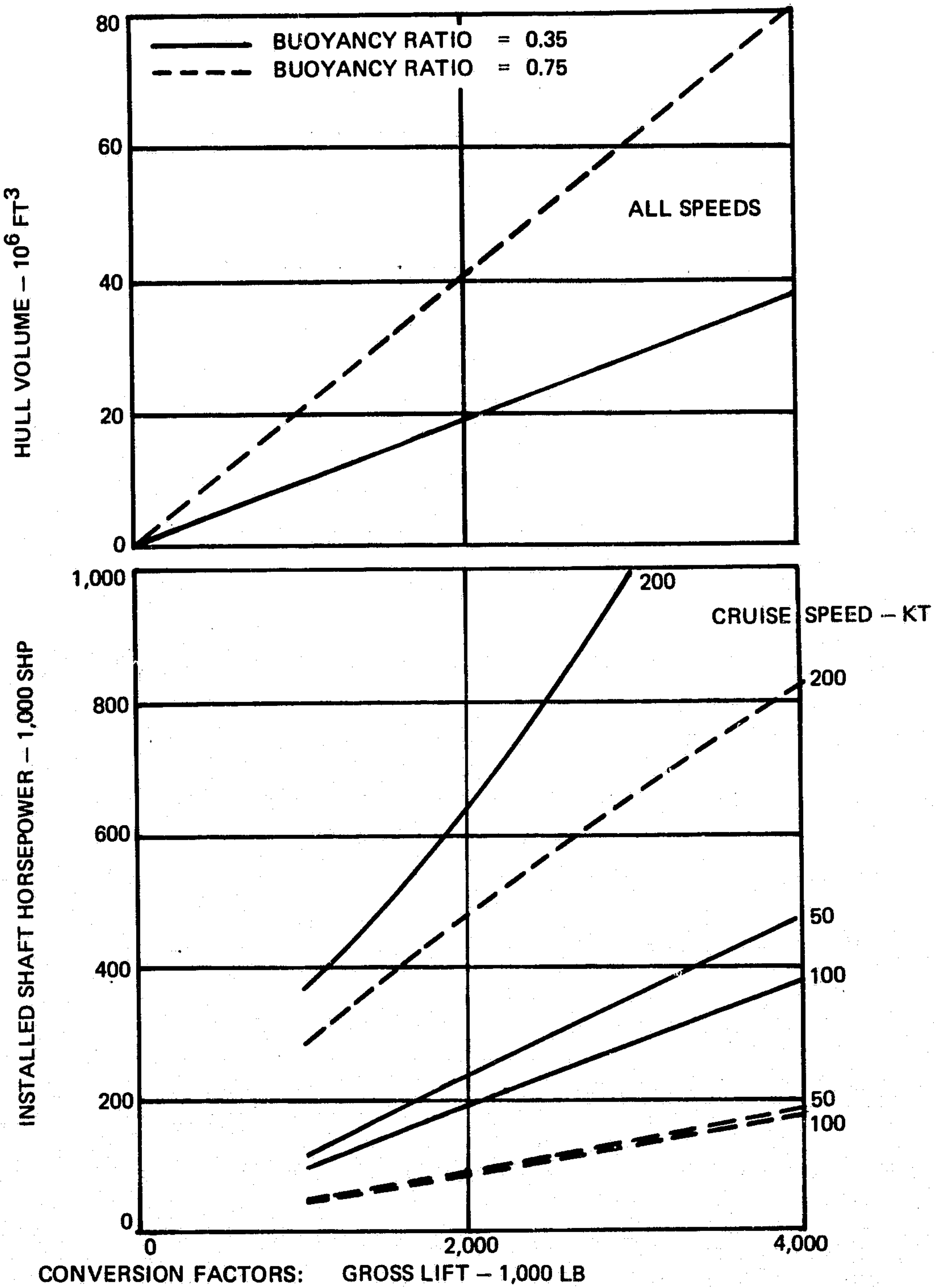
Figure 5–133. Hybrid Airship Trend Study – Heli-Stat, 2,000 N.M. Transcontinental Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
2,000 N.M. = 3,704 KM

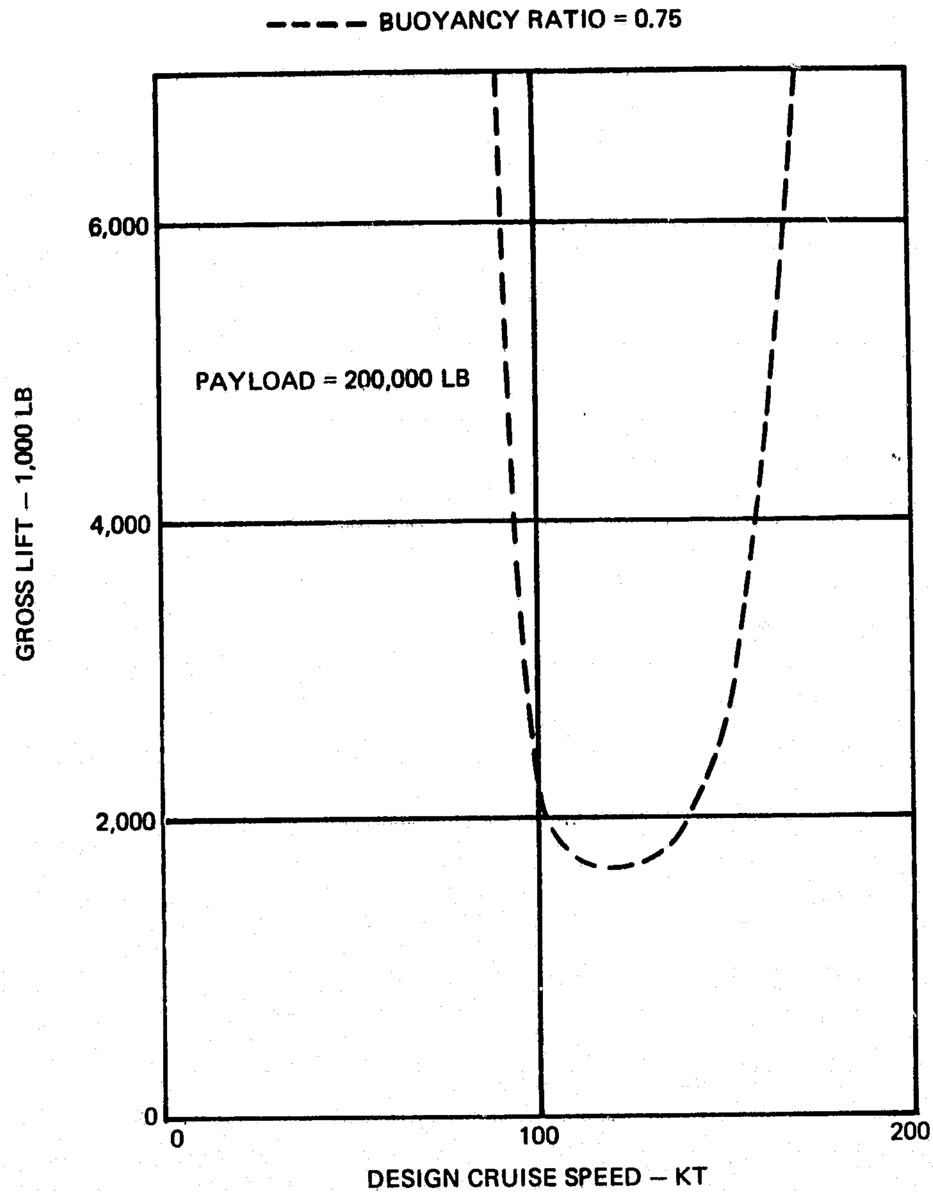
Figure 5–134. Hybrid Airship Trend Study – Heli-Stat, 2,000 N.M. Transcontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
2,000 N.M. = 3,704 KM

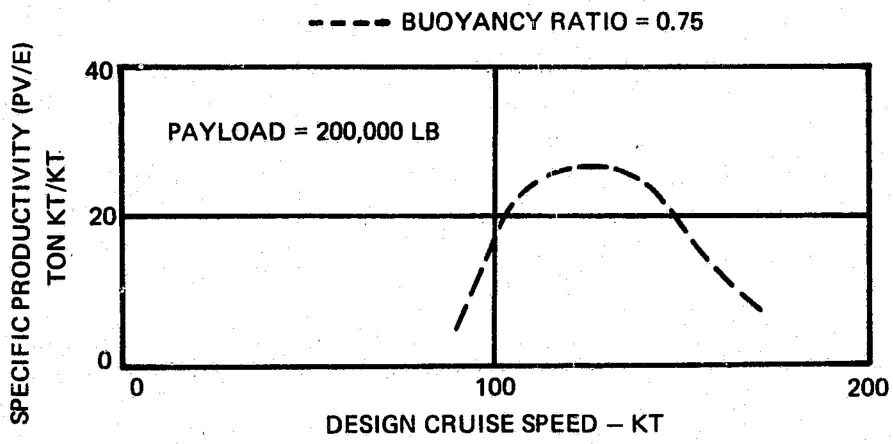
Figure 5–135. Hybrid Airship Trend Study – Heli-Stat, 2,000 N.M. Transcontinental Mission – Configuration Definition



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

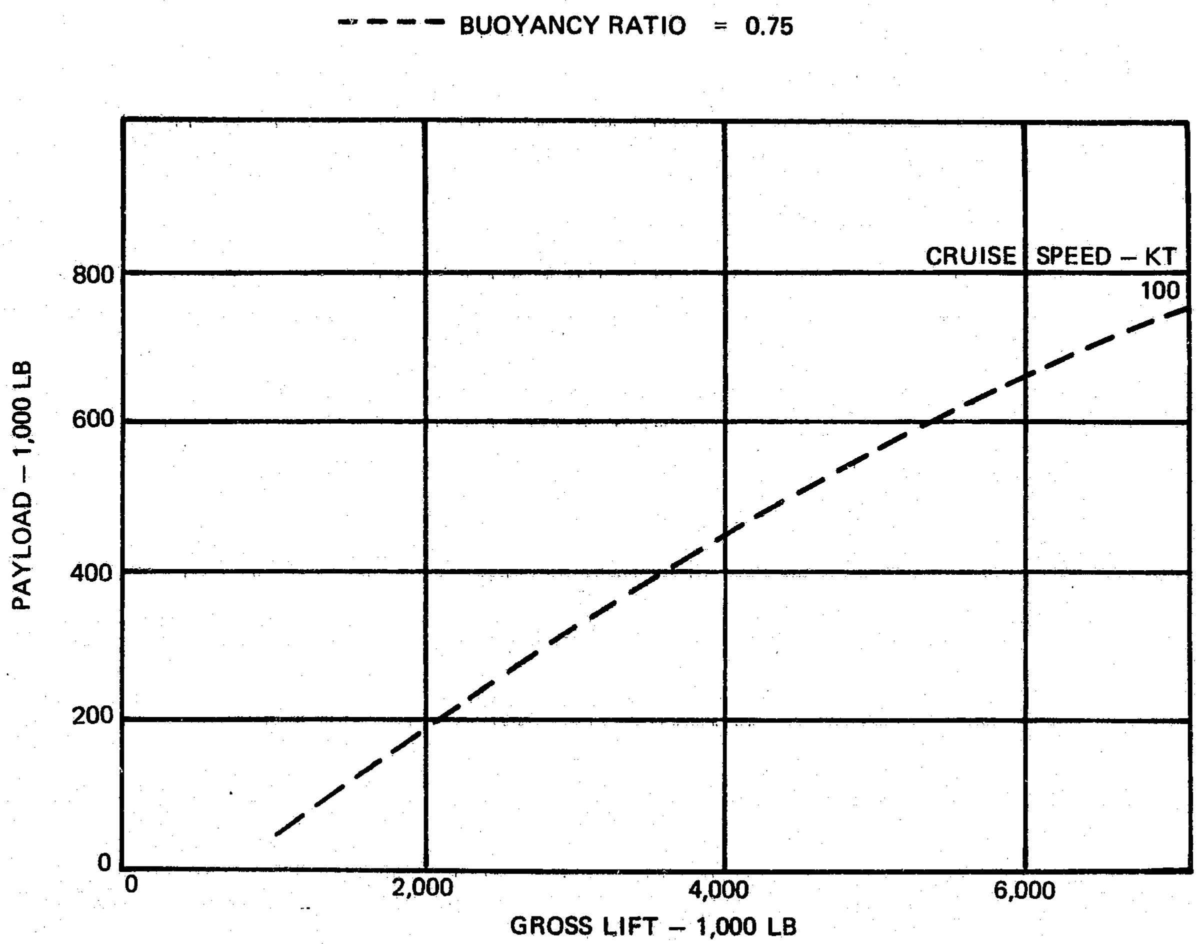
Figure 5–136. Hybrid Airship Trend Study – Heli-Stat, 5,000 N.M. Intercontinental Mission – Gross-Lift Requirement



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 TONKT/TON = 0.514 M.TON x M/S/M.TON
5,000 N.M. = 9,260 KM

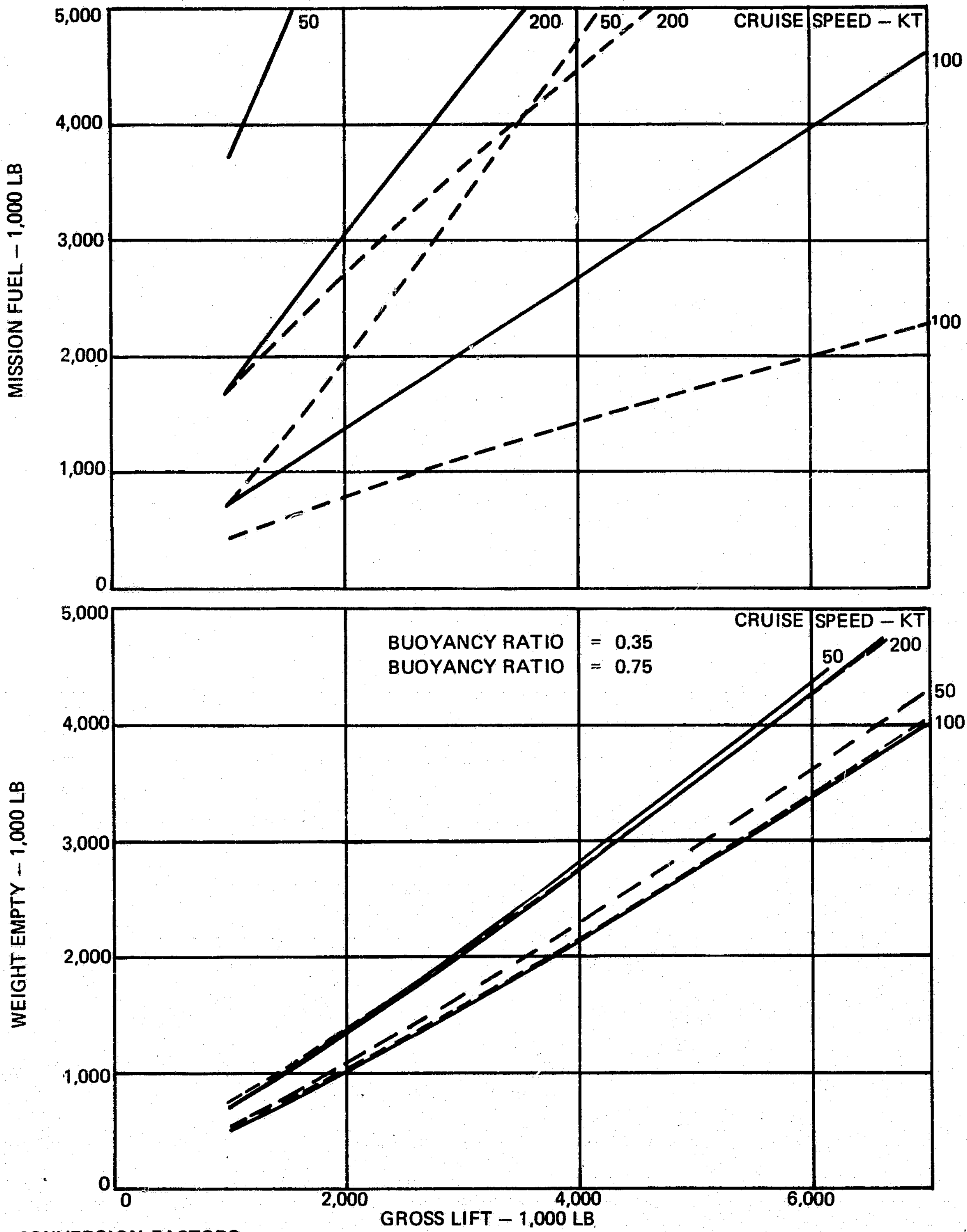
Figure 5–137. Hybrid Airship Trend Study – Heli-Stat, 5,000 N.M. Intercontinental Mission – Specific Productivity



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
5,000 N.M. = 9,260 KM

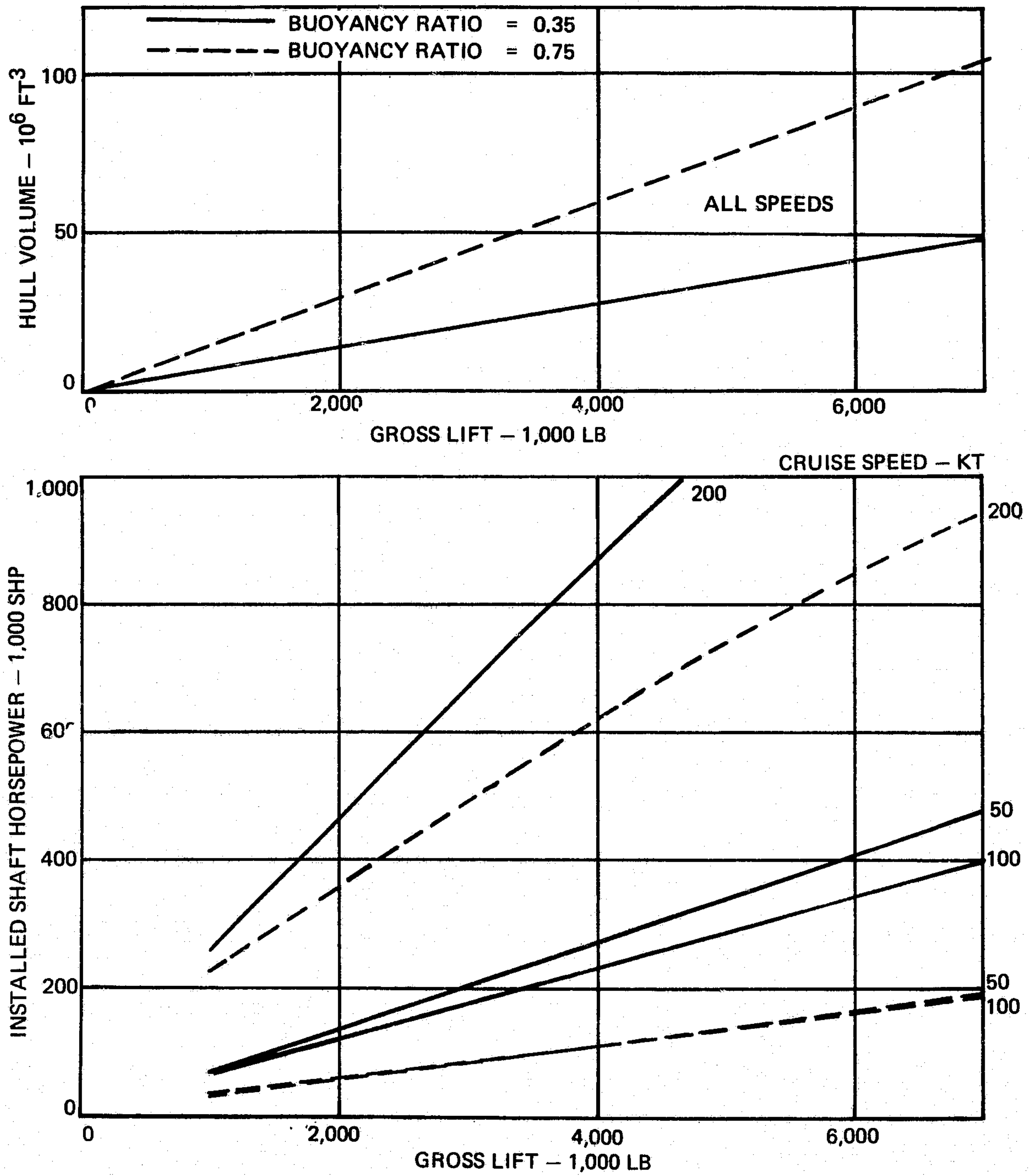
Figure 5–138. Hybrid Airship Trend Study – Heli-Stat, 5,000 N.M. Intercontinental Mission – Payload Capability



CONVERSION FACTORS:

1 LB = 0.454 KG   1 KT = 0.514 M/S   5,000 N.M. = 9,260 KM

Figure 5–139. Hybrid Airship Trend Study – Heli-Stat, 5,000 N.M. Intercontinental Mission – Mission Performance



CONVERSION FACTORS:

1 LB = 0.454 KG
1 KT = 0.514 M/S
1 FT^3 = 0.0283 M^3
5,000 N.M. = 9,260 KM

Figure 5–140. Hybrid Airship Trend Study – Heli-Stat, 5,000 N.M. Intercontinental Mission – Configuration Definition

6. SELECTION OF VEHICLE/MISSION CANDIDATES

6.1 Missions and Mission Requirements

Exploration and evaluation of prospective missions for a modern airship was described and summarized in Paragraph 3 The primary missions considered worthy of further analysis are the freight transport missions described in Table 6-1.

Table 6–I. Mission Profiles for Airship Sizing

PARAMETER	LONG RANGE MISSION TRANSCONTINENTAL	LONG RANGE MISSION INTERCONTINENTAL	SHORT RANGE MISSION
Range	2,000 NM (3,704 km)	5,000 NM (9,260 km)	300 NM (556 km)
Cruise Alt	13,000 ft ISA (3,962 m ISA)	2,000 ft ISA (607 m ISA)	2,000 ft ISA (607 m ISA)
Press. Alt.	15,000 ft ISA (4,572 m ISA)	5,000 ft ISA (1,524 m ISA)	5,000 ft ISA (1,524 m ISA)
Speed	50/100/200 kt (25.7/51.4/102.9 m/s)		50/100/200 kt (25.7/51.4/ 102.9 m/s)
Fuel Reserve	10%		10%
Crew Size	2 x 4		4

Secondary missions, while not considered directly in the mission/vehicle matching, are described in Tables 6-II and 6-III.

6.2 Vehicle/Mission Matching and Selection

Each candidate vehicle concept was sized by means of the CASCOMP computer program for each set of the primary mission requirements. From the resulting weight and performance trends, plots of Specific Productivity (PV/E) were developed for each mission as described in Paragraph 5.4.

Table 6–II. Passenger Mission Profile

2 Routes:	San Francisco - Los Angeles	320 NM (593 km)
	Los Angeles - San Diego	91 NM (169 km)

Fuel Range:	800 NM (1,482 km)
Fuel Reserve:	10%
Cruise Alt.:	1,000 ft (305 m)
Press. Alt.:	3,000 ft (914 m)
Speed:	100 kt (51.4 m/s)
Payload:	250 PAX @ 200 lb (97 kg) + 50,000 lb (22,680 kg) Freight
Crew Size:	8

Table 6–III. Selected USCG Mission Profiles

PARAMETER	AID TO NAVIGATION SHORT MISSION
Range	100 NM (185 km)
Endurance	--
Speed, max/cruise	Best Range Speed + Hover
Payload	40×10^3 lb (18.1×10^3 kg)
Crew	9
Profile	100 NM OUT/1.5 hr Hover/100 NM IN (185 km OUT/1.5 hr Hover/185 km IN)

The maximum specific productivity was then selected for each vehicle concept in each mission and summarized in Table 6-IV through Table 6-VIII.

In every mission case, except the Intercontinental Mission (5000 n.mi. range), the Helipsoid concept appears superior by a wide margin. For the very long range mission, a high buoyancy ratio appears optimum with the conventional non-rigid airship having the highest specific productivity. Since in Paragraph 4., the most promising mission investigated was the 50 ton (45,360 kg) payload freight mission for the transcontinental range of 2000 n.mi. (3700 km), and the Helipsoid has an advantage in PV/E of 37% to more than 100% in that mission, the Helipsoid demonstrates the highest potential for providing a competitive airship capability for future transport missions.

Therefore, the Helipsoid airship flying a 50 ton (45,360 kg) payload in a 2,000 n.mi. (3700 km) transcontinental mission is selected, subject to approval by the NASA, as the most promising vehicle/mission combination for detailed study in Phase II.

The versatility of the Helipsoid Airship was explored by examining that concept in the West Coast Corridor passenger mission and a representative U.S. Coast Guard Mission described in Tables 6-II and 6-III. Helipsoid characteristics for these missions are tabulated in Table 6-IX.

6.3 TECHNICAL FEASIBILITY AND OPERATIONAL ASPECTS

A partially buoyant Helipsoid of the optimum buoyancy ratio has the potential to solve the critical problems facing a future airship development program. Although the optimum buoyancy ratio is mission dependent (as a function of speed, range, etc.), generally the Helipsoid airship with its longitudinally/laterally disposed tilting low disc loading prop/rotors will have a buoyancy ratio near 50%. On this basis, a Helipsoid configuration can be optimized to accomplish the following:

Table 6—IV. Summary of Vehicle Selection for Short Range Mission (50 Ton Payload)

	CONFIGURATION					
	Conv Rigid	Conv Non-Rigid	Deltoid Dynairship	Guppoid Megalifter	Helipsoid	Heli-Stat
Max. PV/E (Knots) (m/s)	89 (45.8)	137 (70.5)	175 (90)	125 (64.2)	200 (102.9)	101 (52)
Speed for Above (Knots) (m/s)	130 (66.9)	95 (48.9)	150 (77.2)	200 (100)	150 (77.2)	105 (54)
Buoyancy Ratio	1.00	1.00	.35	.35	.35	.35
Volume (ft^3) (m^3)	5,200,000 (147,264)	3,650,000 (103,368)	1,300,000 (36,816)	1,680,000 (47,600)	1,200,00 (33,984)	1,500,000 (42,480)
Gross Lift (lb) (kg)	265,000 (120,204)	180,000 (81,648)	198,000 (89,813)	250,000 (114,000)	190,000 (86,184)	220,000 (99,792)
Length (ft) (m)	590 (179.8)	525 (160)	295 (89.9)	400 (122)	260 (79.2)	390 (118.9)
Span (Dia) (ft) (m)	(131) (39.0)	(116) (35.4)	225 (68.6)	(111) (33.9)	145 (44.2)	(87) (26.5)
Summary					SELECTION	

Table 6–V. Summary of Vehicle Selection for Short Range Mission (100 Ton Payload)

CONFIGURATION						
	Conv Rigid	Conv Non-Rigid	Deltoid Dynairship	Guppoid Megalifter	Helipsoid	Heli-Stat
Max. PV/E (Knots) (m/s)	109 (56.1	175 (90)	195 (100.3)	180 (93)	240 (123.5)	127 (65.3)
Speed for (Knots) Above (m/s)	145 (74.6	87 (44.8)	155 (79.7)	200 (102.9)	180 (92.6)	145 (74.6)
Buoyancy Ratio	1.00	1.00	.35	.35	.35	.35
Volume (ft^3) (m^3)	9,800,000 (277,536)	6,200,000 (175,584)	2,600,000 (73,632)	3,250,000 (92,040)	2,700,000 (76,464)	3,200,200 (90,624)
Gross Lift (lb) (kg)	500,000 (226,800)	310,000 (140,616)	381,000 (172,822)	490,000 (222,264)	385,000 (174,636)	462,000 (209,563)
Length (ft) (m)	730 (222.5)	625 (190.5)	365 (111.3)	500 (152.4)	335 (102.1)	500 (152.4)
Span (Dia.) (ft) (m)	(162) (49.4)	(138) (42.1)	283 (86.3)	(140) (42.7)	189 (57.6)	(111) (33.8)
Summary					SELECTION	

Table 6–VI. Summary of Vehicle Selection for Transcontinental Mission (50 Ton Payload)

	CONFIGURATION					
	Conv Rigid	Conv Non-Rigid	Deltoid Dynairship	Guppoid Megalifter	Helipsoid	Heli-Stat
Max. PV/E (Knots) (m/s)	45 (23.1)	65 (33.4)	100 (51.4)	90 (46.3)	137 (70.5)	96 (49.4)
Speed for (Knots) Above (m/s)	82 (42.2)	78 (40.1)	150 (72.2)	150 (77.2)	150 (77.2)	135 (69.4)
Buoyancy Ratio	1.00	1.00	.35	.35	.35	.35
Volume (ft^3) (m^3)	10,000,000 (283,200)	7,600,000 (215,232)	3,900,000 (110,448)	4,800,000 (135,936)	2,300,000 (65,136)	4,000,000 (113,280)
Gross Lift (lb) (kg)	360,000 (163,296)	270,000 (122,472)	420,000 (190,512)	400,000 (181,440)	260,000 (117,936)	440,000 (199,584)
Length (ft) (m)	740 (225.6)	670 (204.2)	420 (128.0)	570 (173.7)	320 (97.5)	540 (164.6)
Span(Dia)(ft) (m)	(165) (50.3)	(149) (45.4)	320 (97.5)	(160) (48.8)	180 (54.9)	(120) (36.6)
Summary					SELECTION	

Table 6–VII. Summary of Vehicle Selection for Transcontinental Mission (100 Ton Payload)

	CONFIGURATION					
	Conv Rigid	Conv Non-Rigid	Deltoid Dynairship	Guppoid Megalifter	Helipsoid	Heli-Stat
Max. PV/E (Knots) (m/s)	54 (27.8)	107 (55)	121 (62.2)	92 (47.3)	135 (69.4)	87 (44.8)
Speed for Above (Knots) (m/s)	82 (42.2)	76 (39.1)	148 (76.1)	154 (79.2)	145 (74.6)	134 (68.9)
Buoyancy Ratio	1.00	1.00	.35	.35	.35	.35
Volume (ft^3) (m^3)	16,500,000 (467,280)	11,000,000 (311,520)	4,900,000 (138,768)	6,000,000 (169,920)	5,100,000 (144,432)	5,730,000 (162,274)
Gross Lift (lb) (kg)	600,000 (272,160)	410,000 (185,976)	520,000 (235,872)	660,000 (299,376)	560,000 (254,016)	610,000 (276,696)
Length (ft) (m)	860 (262.1)	755 (230.1)	460 (140.2)	610 (185.9)	420 (128.0)	610 (185.9)
Span (Dia.) (ft) (m)	(191) (58.2)	(168) (51.2)	350 (106.7)	(170) (51.8)	235 (71.6)	(135) (41.1)
Summary					SELECTION	

Table 6–VIII. Summary of Vehicle Selection for Intercontinental Mission (100 Ton Payload)

	CONFIGURATION					
	Conv Rigid	Conv Non-Rigid	Deltoid Dynairship	Guppoid Megalifter	Helipsoid	Heli-Stat
Max. PV/E (Knots) (m/s)	40 (20.6)	100 (51.4)		48 (24.7)	37 (19)	26 (13.4)
Speed for Above (Knots) (m/s)	63 (32.4)	70 (36)		75 (38.6)	110 (56.6)	126 (64.8)
Buoyancy Ratio	1.00	1.00	N.S.*	.75	.75	.75
Volume (ft^3) (m^3)	12,800,000 (362,496)	10,000,000 (283,200		11,000,000 (311,520)	20,000,000 (556,400)	25,000,000 (708,000)
Gross Lift (lb) (kg)	660,000 (229,376)	500,000 (226,800)		765,000 (347,004)	1,400,000 (635,040)	1,700,000 (771,120)
Length (ft) (m)	800 (243.8)	740 (225.6)		745 (227.1)	655 (199.6)	990 (301.8)
Span (Dia) (ft) (m)	(178) (54.3)	(165) (150.3)		(210) (64.0)	365 (11.3)	(220) (67.1)
Summary						

*N.S. - No solution below 6,000,000 lbs (272,000 kg) Gross Lift

Table 6–IX. Helipsoid Characteristics in Passenger and Surveillance Missions

	Passenger Mission (Payload 100,000#)		USCG (Short) ATN MSN (Payload 50,000#)	
Buoyancy Ratio →	.5	.7	.5	.7
Volume ft³ (m^3)	2.45×10^6 (69.384×10^3)	2.56×10^6 (72.499×10^3)	1.10×10^6 (31.152×10^3)	1.05×10^6 (29.736×10^3)
Gross Lift lb (kg)	274,068 (124,317)	287,068 (130,214)	123,190 (55,879)	119,190 (54,065)
Empty Wt lb (kg)	128,000 (58,061)	145,000 (65,772)	50,000 (22,680	51,000 (23,134)
Mission Fuel lb (kg)	42,000 (19,051)	38,000 (17,237)	18,000 (8,165)	13,000 (5,897)
Installed Power HP	14,100	11,500	8,700	7,000
Length ft (m)	322 (98.1)	369 (112.5)	254 (77.4)	289 (88.1)
Width (Span) ft (m)	184 (56.1)	209 (63.7)	147 (44.8)	164 (50.0)

6.3.1 Eliminate Ballast and Ballast Recovery Systems

Since weight losses due to fuel burnoff can be counteracted by aerodynamic trimming in cruise flight and prop/rotor collective pitch in low speed flight, no water recovery apparatus will be required. In addition (depending on the mission optimization), transfer of payload may also be accomplished without ballast - replacement systems.

6.3.2 Full Low-Speed Controllability

Depending on the mission requirements, a full VTOL capability may be provided with the attendant implications of full low-speed controllability provided by proper utilization of the tilting prop/rotors. Provision of this capability in addition to the low buoyant lift can remove the airship's susceptibility to wind, eliminate requirements for ground handling crews and equipment, and generally improve the airship's operating aspects. Since strong control power is available, as well as the availability of dynamic lift trimming, weather and icing constraints should be eliminated.

6.4 ECONOMIC CONSIDERATIONS

Although costing is a part of the Phase II program, some indication of the trend in direct and indirect operating costs may be gained from the relationship of maximum specific productivity for the Helipsoid compared to the conventional rigid and non-rigid airships. Since specific productivity (PV/E) is a strong indicator of relative Direct Operating Costs (D.O.C.), a Helipsoid would appear to have a reduced D.O.C. (from that of conventional airships) on the order of 25% to 50% flying at a considerably higher cruise speed. Elimination or reduction of the ground handling crews and equipment will help to reduce the operators Indirect Operating Costs (I.O.C.)

REFERENCES

1. Blakemore, T.L. and WattersPagon, W., PRESSURE AIRSHIPS, The Ronald Press Company, 1927.

2. Webb, L.N., FOREIGN-BUILT AIRSHIPS IN U.S. SERVICE 1919 TO 1939, A.A.H.S. Journal, Spring, 1968.

3. Brooks, P.W., HISTORIC AIRSHIPS, New York Graphic Society, Ltd., Greenwich, Ct., 1973.

4. Beaubois, H., AIRSHIPS, AN ILLUSTRATED HISTORY, MacDonald and Jane's, London, 1974.

5. Janes, ALL THE WORLDS AIRCRAFT, 1913

6. Janes, ALL THE WORLDS AIRCRAFT, 1919

7. vonKirshbaum, W. and vonSchiller, H. in BERICHT UEBER DAS LUFTSCHIFF-KOLLOQUIUM DER DGLR AM 6 APRIL 1972 IN STUTTGART (Proceedings from the German Air and Space Society Airship Colloquium on 6 April 1972), DLR Mitt. 72-17, Deutsche Gesellshaft for Luft-und Raumfahrt, Cologne, 1972.

8. THEY WERE DEPENDABLE-AIRSHIP OPERATION IN WORLD WAR II, U. S. Naval Air Station, Lakehurst, N.J., 2nd Edition, 1946.

9. Smith, R.K., THE AIRSHIPS AKRON AND MACON, Naval Institute Press, Annapolis, Md., 1965.

10. Carten, A.S. Editor, PROCEEDINGS, EIGHT AFCRL SCIENTIFIC BALLOON SYMPOSIUM, 30 SEPTEMBER TO 3 OCTOBER 1974, AFCRL-TR-74-0393, 21 August 1974, Air Force Cambridge Research Laboratories, Hanscom AFB, MA 01730, 1974.

11. Vittek, Jr., J.F. Editor, PROCEEDINGS OF THE INTERAGENCY WORKSHOP ON LIGHTER THAN AIR VEHICLES, FTL Report R75-2, January 1975, M.I.T. Flight Transportation Laboratory, Cambridge, Ma 02139, 1975.

12. RIGID AIRSHIP MANUAL 1927, U.S. Government Printing Office, Washington, D.C., 1927.

13. Burgess, C.P., AIRSHIP DESIGN, The Ronald Press Company, New York, N.Y., 1927.

14. U.S. NAVAL AVIATION 1910-1960, NAVWEPS CO-80P-1, Prepared at the direction of the Deputy Chief of Naval Operation (Air) and the Chief of Bureau of Naval Weapons, 1960.

15. Gibbons, W.A. and Smith. O.H., INVESTIGATION OF BALLOON AND AEROPLANE FABRICS, Part I, NACA TR No. 6

16. Horton, E., THE AGE OF THE AIRSHIP, Henry Regnery Company, Chicago, Il., 1973.

17. Campbell, H., CONTROVERSY IN SOVIET R&D: THE AIRSHIP CASE STUDY, Rand Corp., R-1001-PR, October 1972, AD-769910.

18. Stepler, R.M., RETURN TO LIGHTER-THAN-AIR TRANSPORTATION FOR MILITARY AND CIVILIAN APPLICATION, Defense System Management School, Fort Belvoir, Va, November 1973, AD-776363.

19. Havill, C.H., THE DRAG OF AIRSHIPS, NACA TN No. 247.

20. Havill, C.D. and Williams, L.J., SOME APPLICATIONS OF BOUYANCY SYSTEMS AND PARAWINGS TO REPLACE CONVENTIONAL AND PROPOSED TRANSPORTATION SYSTEMS, Proceedings on Intersociety Conference on Transportation, Washington, D.C., May 31-June 2, 1972. SAE, Inc., New York, N.Y.

21. Dorand, W.F. Editor-in-Chief, AERODYNAMIC THEORY, VOLUME VI, California Institute of Technology, 1943.

22. Fitz, C.D., Egen, R.A., Frankisky, J.O., and Blue, B.K., AN EVALUATION OF THE FEASIBILITY OF UTILIZING BALLOON SYSTEMS FOR THE SHIP-TO-SHORE TRANSPORT OF MILITARY CARGO, June 1973, Battelle Columbus Laboratories, AD-765352.

23. Clemments, E.W. and O'Hara, G.J., THE NAVY RIGID AIRSHIP, July 1972, Naval Research Laboratory, Washington, D.C.

24. Davidson, Jr., A.R., LEAK DETECTION OF LARGE PRESSURIZED SPHERICAL BALLOONS, Vitro Laboratories Technical Report 02091.01-1, 30 April 1968, AD-670886.

25. Seemann, G.R., Harris, G.L., Brown G.J. and Collian, C.A., REMOTELY PILOTED MINI-BLIMPS FOR URBAN APPLICATIONS. Astronautics and Aeronautics, February 1974.

26. U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of the Census. 1967 CENSUS OF TRANSPORTATION COMMODITY TRANSPORTATION SURVEY.

27. U.S. Department of Commerce, Bureau of Accounts, Interstate Commerce Commission, FREIGHT COMMODITY STATISTICS FOR MOTOR CARRIERS OF PROPERTY FOR 1972.

28. U.S. Department of Commerce, Bureau of Accounts, Interstate Commerce Commission, FREIGHT COMMODITY STATISTICS FOR CLASS 1 RAILROADS FOR 1973.

29. U.S. Department of Commerce, Bureau of Domestic Commerce, INDUSTRY PROFILES 1958-1969.

30. U.S. Department of Commerce, Social and Economic Statistics Administration, Bureau of Census, NATIONAL TRAVEL SURVEY, TRAVEL DURING 1972, 1972 CENSUS OF TRANSPORTATION.

31. Brooks, F., Brown, M., Fraiz, W., Mutter, R., Swanson, C., Thatcher, R., and Watson, J., HIGH SPEED GROUND TRANSPORTATION ALTERNATIVES STUDY, Mitre Corporation, Washington, D.C., December 28, 1972.

32. FINAL INFORMATION RESPONSE BY THE BOEING COMPANY IN NORTH EAST CORRIDOR VTOL INVESTIGATION, 10 February, 1969, CAB Docket 19078.

33. Burlingame, M.V., McKinley G.W. and Vandoveer, F.E., ECONOMICS OF GAS TRANSMISSION, CHAPTER 4, GAS ENGINEERS HANDBOOK, The Industrial Press, New York, 1965.

34. Sonstegaard, M.H., AIRSHIP VS. PIPELINES FOR NATURAL GAS TRANSPORTATION, Published by the author 1970, Fayetteville, Ar.

35. Sonstegaard, M.H., AIRSHIP TRANSPORTATION OF COMMERCIAL GASES: PRELIMINARY OPTIMIZATION AND COST ESTIMATION. ASME Paper 72-Pet-41, 1972.

36. Sonstegaard, M.H., TRANSPORTING COMMERCIAL GASES BY AIRSHIP, Published by the author, Fayetteville, Ar.

37. Hearings Before the Committee on Aeronautical and Space Sciences, United States Senate, Ninety-Third Congress, Second Session, July 16 and 18, 1974. ADVANCED AERONAUTICAL CONCEPTS, 38-2660 U.S. Government Printing Office, Washington, 1974.

38. Rosendahl, C.E. and Vaeth, J.G., AIRSHIP, Encyclopaedia Brittanica, Vol. 1, 1963.

39. Schneider, J.J., FUTURE LIGHTER THAN AIR CONCEPTS, SAE Air Transportation Meeting, Hartford, Ct, May 6-8, 1975.

40. Sonstegaard, M.H., TRANSPORTING GAS BY AIRSHIP, Mechanical Engineering, June 1973.

41. Wilkinson, P. H., AIRCRAFT ENGINES OF THE WORLD - 1945, Paul H. Wilkinson, New York, New York, 1945.

42. Wilkinson, P. H., AIRCRAFT ENGINES OF THE WORLD - 1970, Paul H. Wilkinson, Washington, D. C., 1970.

43. Locke, F. W. S., Jr., A PRELIMINARY STUDY OF A NUCLEAR POWERED AIRSHIP, Report No. DR-1649, Bureau of Aeronautics, Navy Department, Washington, D. C., April, 1954.

44. Rom, F.E., AIRBREATHING NUCLEAR PROPULSION, A NEW LOOK, TM-X-67837, NASA, Cleveland, Ohio, 1971.

45. Liberatore, E.K., STEAM POWERED HELICOPTER MODEL STH-1 DESIGN AND PERFORMANCE, Report 107PD-1, Steamotive Incorporated, Tempe, Arizona, 1 May 1974.

46. Hoess, J.A., and Stahman, R.C., UNCONVENTIONAL THERMAL, MECHANICAL, AND NUCLEAR LOW-POLLUTION POTENTIAL POWER SOURCES FOR URBAN VEHICLES, SAE 690231, Society of Automotive Engineers, 1969.

47. Roensch, M.M., THE AUTOMOTIVE ENGINE - TODAY AND TOMORROW, SAE 710845, Society of Automotive Engineers, 1971.

48. U. S. Department of the Interior, Bureau of Mines Bulletin 650, MINERAL FACTS AND PROBLEMS, 1970 EDITION.

49. U. S. Bureau of Census, 1963 CENSUS OF MINERAL INDUSTRIES, CRUDE PETROLEUM AND NATURAL GAS, Industry Statistics MIC 63(1)-BB, January 1967.

50. American Gas Association, Department of Statistics, 1973 GAS FACTS.

51. Matheson Gas Products, MATHESON GAS DATA BOOK, Fifth Edition, Matheson Gas Products, Hackensack, NJ, 1971.

52. Papst, H.E.R., AIRSHIP, U. S. Patent 3,456,903, 22 July 1969.

53. U. S. Federal Power Commission, NATURAL GAS SURVEY, VOLUME I, CHAPTER 10, FUTURE GAS SUPPLIES FROM ALTERNATIVE SOURCES.

54. International Gas Union, PAPERS MEMOIRES, FOURTH INTERNATIONAL CONFERENCE ON LIQUEFIED NATURAL GAS, Institute of Gas Technology, Chicago, Il.

55. U.S. Department of the Interior, BUREAU OF MINES, MINERALS YEARBOOK, 1972.

56. U. S. Department of the Interior, Bureau of Mines, MINERAL INDUSTRY SURVEYS, NATURAL GAS PRODUCTION AND CONSUMPTION: 1973.

57. Vandoveer, F.E., GASEOUS FUELS, CHAPTER 2, GAS ENGINES HANDBOOK, The Industrial Press, New York, 1965.

58. Under the Authority of the Council of the Royal Aeronautical Society, HANDBOOK OF AERONAUTICS, Gale and Polden, Ltd., London, 1931.

59. Teichmann, K., AIRPLANE DESIGN MANUAL, Pitman Publishing Co., 1942.

60. Ebner, H., THE PRESENT STATUS OF AIRSHIP CONSTRUCTORS, ESPECIALLY OF AIRSHIP-FRAMING CONSTRUCTION, NACA Technical Memorandum, No. 872, Washington, D.C., July 1938.

61. Ricle, J., ASSESSING THE PROMISE OF NEW MATERIALS FOR VTOL AIRCRAFT, Vertiflite, December 1968.

62. Loudy, E., METAL AIRPLANE STRUCTURES, Kenley Publishing Co., 1938.

63. Dunlap and Associates, Inc., HUMAN FACTORS IN THE DESIGN OF AIRSHIPS, U. S. Navy Special Devices Center, Report SDC 641-2-9, June 1950.

64. Hartos, G.R., SUMMARY COST ANALYSIS MODEL AND DATA BASE, D170-10007-2, Boeing Vertol, Phila., 1970.

65. Schlichting, H., BOUNDARY - LAYER THEORY, McGraw-Hill Book Company, New York, 1968.

66. Gabriel, E.A., DRAG ESTIMATION OF V/STOL AIRCRAFT, D8-2994-1, Boeing Vertol, Phila., 1968.

67. GENERALIZED METHOD OF PROPELLER PERFORMANCE ESTIMATION, Hamilton Standard, Division of United Aircraft, Windsor Locks, Ct., 1963.

68. GENERALIZED METHOD OF SCHROUDED PROPELLER PERFORMANCE ESTIMATION, PDB 6220, Hamilton Standard, Division of United Aircraft, Windsor Locks, Ct., 1963.

69. McLamare, H.C., WIND TUNNEL TESTS OF A 1/20 - SCALE AIRSHIP MODEL WITH STERN PROPELLERS, NASA Technical Note D-1026, 1962.

70. Boatwright, D.W. and Cornish III, J.J., APPLICATION OF FULL SCALE BOUNDARY LAYER REASSESSMENTS TO DRAG REDUCTION OF AIRSHIPS, Research Report No. 28, The Aerophysics Department, Mississippi State University, 1960.

71. Hoyt, J.W., A SURVEY OF HYDRODYNAMIC FRICTION-REDUCTION TECHNIQUES, AIAA Paper No. 67-431, American Institute of Aeronautics and Astronautics, New York, 1967.

72. Wells, C.S. Editor, VISCOUS DRAG REDUCTION, Plenum Press, New York, 1969.

73. Flax, A.H. and Lawrence, H.R., THE AERODYNAMICS OF LOW-ASPECT-RATIO WINGS AND WING-BODY COMBINATION, Report No. CAL-37, Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y., 1951.

74. Santos-Dumont, A., MY AIRSHIPS, Dover, Reprint of 1973, originally "Dans l'air," 1904.

75. Berget, A., THE CONQUEST OF THE AIR, G. P. Putnam's Sons, 1909.

76. Zahm, A.F., AERIAL NAVIGATION, D. Appleton and Co., 1911.

77. Headley, J.T., THE GREAT REBELLION, The National Tribune, Washington, D.C., 1898.

78. Allen, H., THE STORY OF THE AIRSHIP, Goodyear Tire and Rubber Co., 1931.

79. Winter, Lumen and Degner, Glenn, MINUTE EPICS OF FLIGHT, Grosset and Dunlap, 1933.

80. Anon, FLIGHT - A PICTORIAL HISTORY OF AVIATION, Year Incorporated, Los Angeles, Cal., 1953.

APPENDIX A

DESCRIPTION OF LTA VEHICLE CONCEPTS

Recent activities in the lighter than air field have resulted in many different approaches to the development of an advanced airship. Although grouping of these concepts has been accomplished for purposes of selection of representative concepts for evaluation, this section endeavors to describe all known variants uncovered in the literature search. Each concept sketch is accompanied with a thumbnail description and source data reference.

The concepts are presented in alphabetical order within each sub-group as defined in Figure 5-1 of the report.

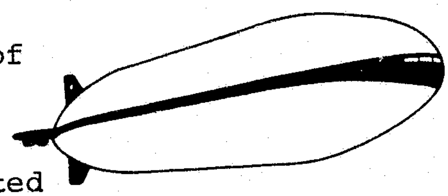
A-1. FULLY BUOYANT CONCEPTS

A-1.1 Rigid

All of the recent rigid concepts seek to improve on the early rigids by variations in propulsion and control or structural design techniques. These variants are:

1) Aerospace Developments (Ref. 1)*

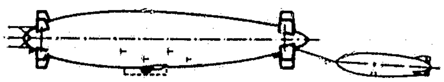
This 100 million ft^3 (2.83 million m^3), 1800 ft (549 m) long relatively conventional looking airship is under investigation for transport of natural gas. Primary structure is of stainless steel sandwich type using Kevlar for the inner core. Turboprops and propellers are mounted on the tail surfaces. A flexible membrane separates air and gas within the hull.



* Reference numbers refer to List of References in this Appendix.

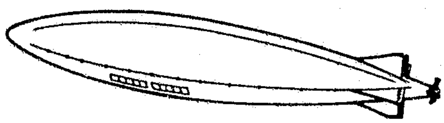
2) Airfloat Transport (Ref. 2)

This study of a heavy lift airship was initiated in 1970 and is still under consideration. Propulsion and empennage units are mounted both forward and aft to provide vectoring/aerodynamic control. The hoisting system is designed to transfer ballast during payload hook-up or release. A separate "fuel-blimp" carries gaseous fuel for the 10 turboprop engines.



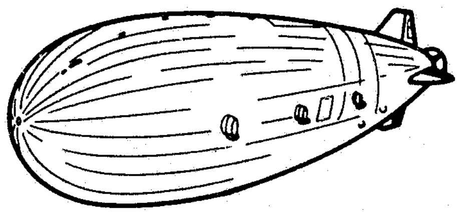
3) Boston University (Ref. 3)

Professor Morse of Boston University has been proposing a nuclear powered typically conventional airship for some years. An aft-mounted coaxial pro-peller provides propulsion.



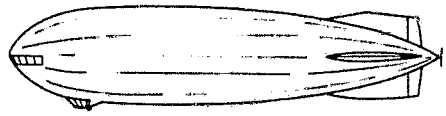
4) Cargo Airships (Ref. 4)

In the early 1970's, Cargo Airships proposed use of large rigid airships in a freight transport role.



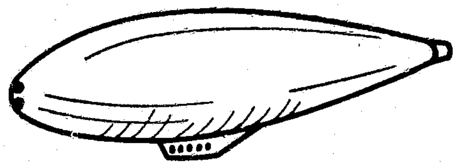
5) Conrad CA-1 (Ref. 5)

This privately funded 225 ft. (69 m) long rigid airship has been under development for the past several years. The hull is of welded aluminum tubing containing ten Mylar helium cells. The cover is to be of laminated Mylar.



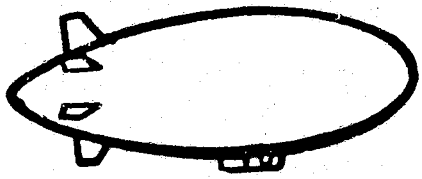
6) Mikhalev (Ref. 6)

This mid-1960's Soviet project was a heated-air rigid airship using exhaust gases from turbojet engines in the nose to both heat the lifting medium-air - and provide propulsion through a swivelling nozzle in the tail. Temperature of the air is raised to 500-700°F, (260-371°C) within an insulated hull structure.



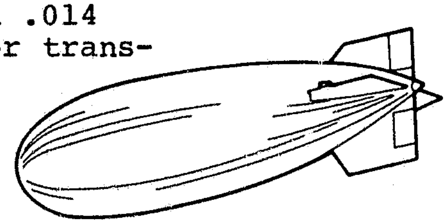
7) SCACI Metalclad (Ref. 7)

Under the auspices of the Southern California Aviation Council, the early Metalclad Aircraft Development Co. ZMC-2) concept is being revived. The pressure-rigid airship features an Alclad covering with light framing (for depressurized state on the ground).



8) SLATE SMD-100 (Ref. 8, 9)

Another Metalclad concept is the SLATE SMD-100 of the early 1960's. This is an 8.67 million ft^3 (.25 million m^3) hull with an .014 in.,.4 mm Alclad skin proposed for transport of the Saturn booster components from manufacturing plants to Cape Canaveral (Kennedy).



9) Veress ALV-1 (Ref. 10)

A 1967 proposal is this nuclear powered airship featuring the boundary layer energizing propulsion system. Air is drawn in at the nose and ejected along the hull to reduce drag and provide propulsive thrust.

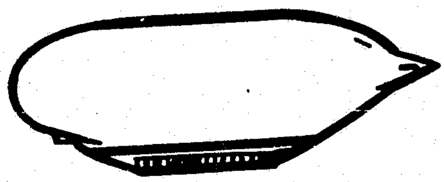
A-1.2 Semi-Rigid

1) Novosibirsk 2 (Ref. 6)

Another mid-1960 Soviet project was this twin engine semi-rigid for carrying up to 30 ton payloads.

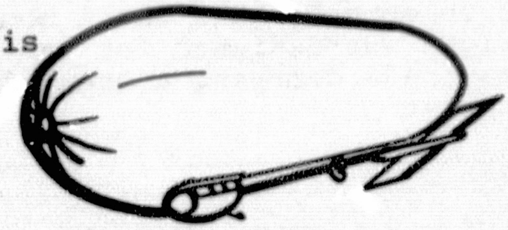
2) Papst (Ref. 11, 12)

Herman Papst has been investigating methods of transporting natural gas for many years and holds many patents on airship concepts. This semi-rigid concept has a double-walled skin for insulation and flexible diaphragms for carrying separately steam or heated air.



3) Tucker TX-1 (Ref. 13)

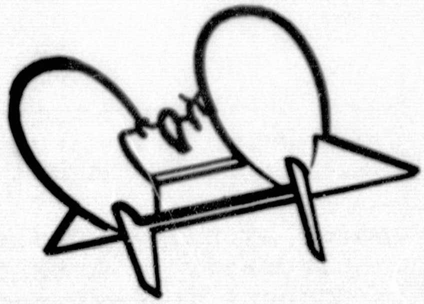
This 88 ft. (27 m) long prototype is under construction at the present time. Initial testing will be conducted using hydrogen.



A-1.3 Non-Rigid

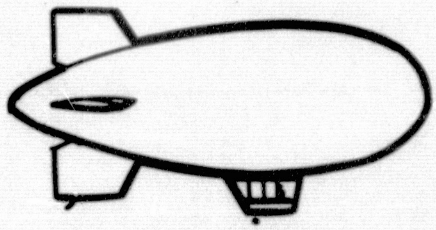
1) Balleyguier LGV (Ref. 14, 15)

This twin-hull concept is proposed for heavy lift missions. The two balloons are connected by a wing having a control station and propulsion system. During load pickup and release, a tethering system is employed for precise control.



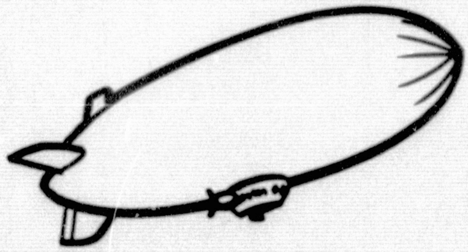
2) Canadian CAD-1 (Ref. 16)

In development in Canada, this 120 ft. (37 m) long prototype is expected to fly in 1975 to gain training and operational experience prior to embarking on development of large commercial airships.



3) Goodyear Blimp

Goodyear, of course, is operating several small non-rigids in its advertising and public relations activities



4) Novosibirsk 1 (Ref. 6)

Another rumored mid-1960's development, this small non-rigid was designed for one ton payloads carrying a crew of three.

5) Raven STAR (Ref. 17)

Designed for the sport enthusiast, this 120 ft. (37 m) long non-rigid is inflated with hot air by an on-board heat generator.

6) Sonstegaard Concept (Ref. 18, 19)

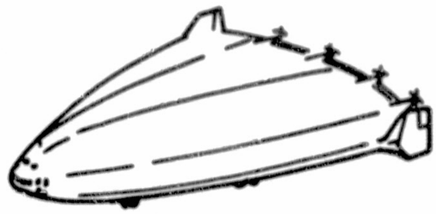
Proposed by Miles Sonstegaard of the University of Arkansas, this concept is designed for the transport of buoyant gases such as natural gas.

A-2. PARTIALLY BUOYANT CONCEPT

A-2.1 STOL Lifting Body Concepts

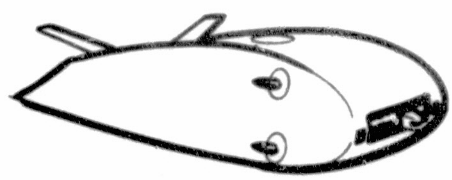
1) Aereon Dynairship (Ref. 20,21)

This deltoid configuration has been under development since 1967. A small, single place test bed (non-buoyant) has been flown. The body structure would be a rigid-type and with the propulsion concept shown would have STOL landing characteristics. By suitable rearrangement of tilting proprotors, a VTOL variant is possible providing adequate power is installed.



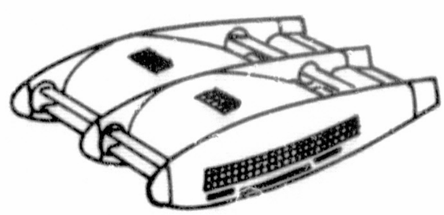
2) Carnegie-Mellon Study (Ref. 22)

Senior students at Carnegie-Mellon University developed this concept during the 1967-68 school year. A lifting body type with buoyant lift as well as a central ducted fan; this concept was propelled by four turboprops.



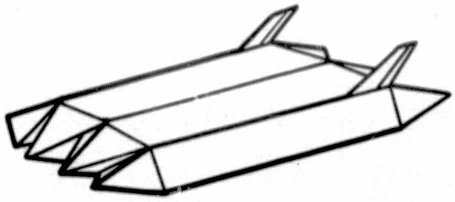
3) Delphin-Luftschiff (Ref. 23)

This 1970 German concept combines a rectangular lifting body with buoyant lift and shaft-driven cyclogyros forward and aft. The cyclogyros are proposed for both propulsion and auxiliary lift as well as control.



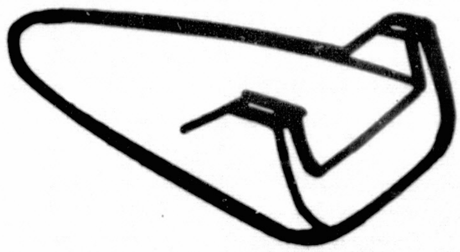
4) Dynapod (Ref. 24)

This 1970 concept, proposed by A. Clyde Davenport, is a variable density airship system which expands or contracts to optimize lift for varying weight and altitude. The hull is composed of several four-sided rigid panel members having internal diaphragms for gas-air separation.



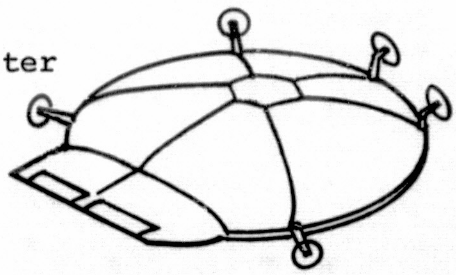
5) Havill Lifting Body (Ref. 25)

Proposed by C. Dewey Havill, this is a deltoid concept based on technology developed for space reentry systems.



6) West Associates Skyship (Ref. 26)

Presently being investigated in Great Britain, the Skyship is proposed as a 700 ft. (213 m) diameter discus-shaped vehicle. Ten tilting propellers are driven by ten R-R Tyne turboprop engines (modified to use methane) providing propulsion and control. Structure is rigid and nineteen helium gas bags provide the buoyancy.



C-5

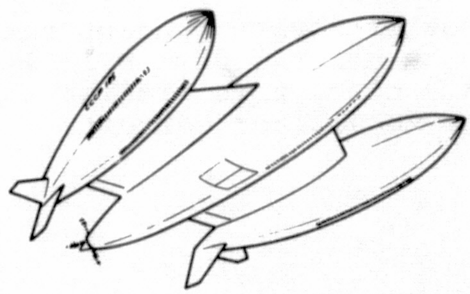
A-2.2 STOL Auxiliary Wing(s) Concept

1) Aereon Triple Hull (Ref. 20, 27, 28)

This 1959 development followed the principles of the Civil War era Aereon flown over New York City by Dr. Solomon Andrews. The recent test bed was, however, propelled by a pusher rotor. Flight testing was not pursued due to a ground accident and development was terminated in favor of the Dynairship approach.

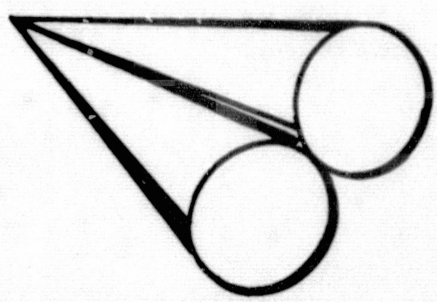
2) Ercik 3 Triple Hull (Ref. 6)

This concept was rumored to be under development in the Soviet Union in 1967 but nothing has appeared since. A large pusher rotor was to be mounted on the large center hull. Two smaller hulls on the sides were connected to the central hull by low aspect ratio wing panels.



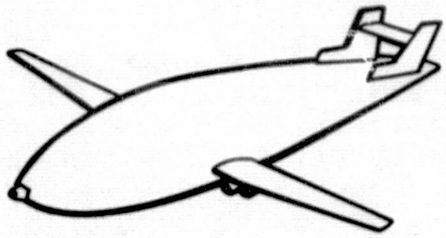
3) Havill Parawing (Ref. 29)

This inflatable Parawing concept proposed by C. Dewey Havill features use of hot air for takeoff in an expanded lifting body. After takeoff and transition, the air is cooled down and the concept flies as a low drag parawing.



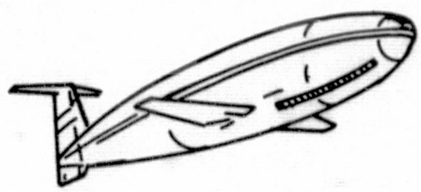
4) Megalifter (Ref. 30)

This proposed concept features a typical airship hull (or variant) combined with a high aspect ratio auxiliary wing. Although concept shown is a STOL powered by four high bypass turbofans, with suitable arrangement of tilting prop-rotors and adequate power, a VTOL variant is possible. As proposed, the rigid frame of geodetic type is external to the helium cells. The cells are full at sea level and pressure is allowed to build up to as much as 10-14 psi (6.89-9.65 N/m^2) at pressure altitude without loss of helium.



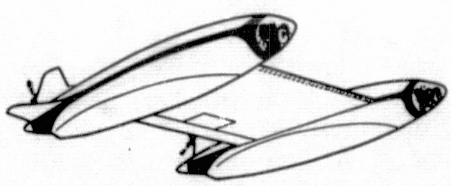
5) Soviet Inflatowing

Another Soviet concept rumored to be under study in 1967, this concept is similar to the Megalifter concept.



6) Twin Hull Concept (Ref. 31)

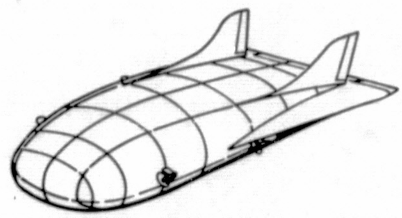
This 1956 concept has also been recently proposed for heavy lift forestry work by a British organization.



A-2.3 VTOL Lifting Body Concepts

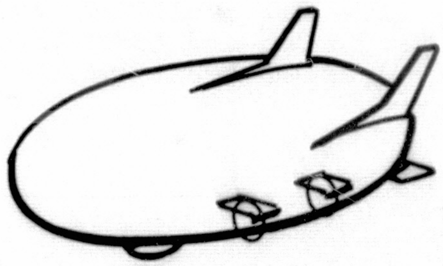
1) Boeing Deltoid

This hybrid concept has a low aspect ratio highly swept delta shape with a thickness ratio of about 21%. Body structure would be of rigid-type construction with a multi-cell lifting gas arrangement. Engines are inboard and drive tilting variable pitch prop-rotors. Depending on the power installed, and buoyancy ratio, the concept may be either VTOL or STOL.



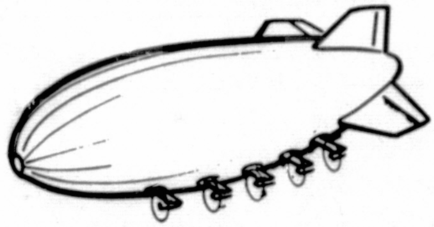
2) Boeing Helipsoid

The ellipsoid was chosen as a suitable compromise structural and aerodynamic shape between the cylindrical airship and the deltoid shape. The concept would probably be most suited to a rigid structure with a multi-cell arrangement. The concept endeavors to reduce length and height to facilitate manufacture and hangaring as well as better matching the typical (helicopter) landing pad.



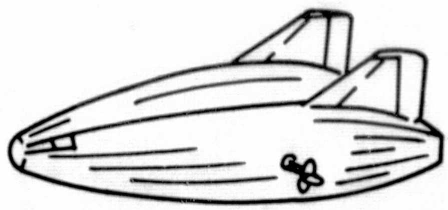
3) Goodyear Dynastat (Ref. 32)

This is a non-rigid (or semi-rigid) variant of the deltoid class as proposed by Goodyear. Similar in concept to the very early Astra Torres designs, it features as many as 3 to 7 lobes in a flattened, low-aspect ratio, helium filled envelope.



4) NASA/Douglas Deltoid (Ref. 33)

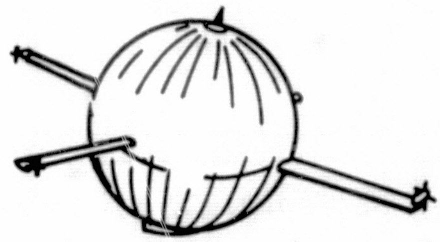
Another variant of the deltoid class is this concept suggested by NASA-Langley researchers and L. L. Douglas of Boeing Vertol. The basic feature of this concept is the use of a single large diameter tilting rotor (on each side) providing through collective and cyclic pitch the auxiliary lift and trim lift required as well as propulsive thrust.



A-2.4 VTOL Combined/Integrated Concepts

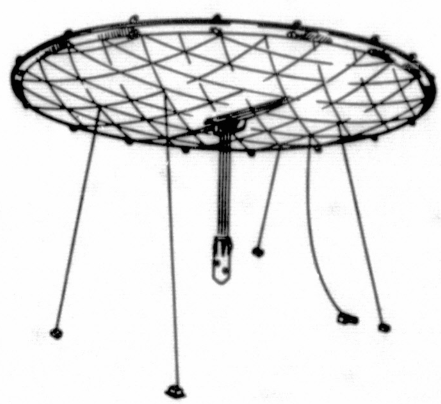
1) All-American Aerocrane (Ref. 34)

This concept is under development in small-scale form under U.S. Navy funding and also by private funding. Variable incidence, propeller-driven wings are mounted to a large diameter balloon. Both balloon and the wing-rotor turn together at low RPM (about 200 fps (61 m/s) tip speed) to provide combined aerostatic and rotor lift. In a non-carrying version, a suspended stabilized cabin is provided for the crew. The concept provides buoyant lift equal to the empty weight, fuel and half the nominal payload. Rotor lift, either positive or negative, is used for the remainder of the weight. When payload is removed, negative lift is adjusted to maintain altitude. When the rotor is stopped, the concept will either be free-ballooned or be tethered to the ground station.



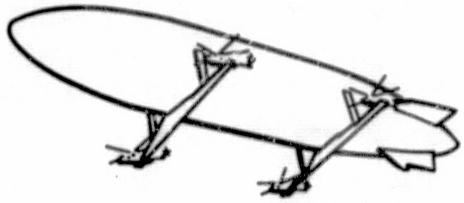
2) C.N.R.S. Pegase and Titan (Ref. 35)

This lens-shaped giant aerostat is under development in France by a consertium of various equipment manufacturers led by C.N.R.S. Several versions have been investigated with varying propulsion and control schemes. The Pegase was originally intended for a high altitude telecommunications relay system, but the derivative Titan is a very heavy lift crane concept as shown.



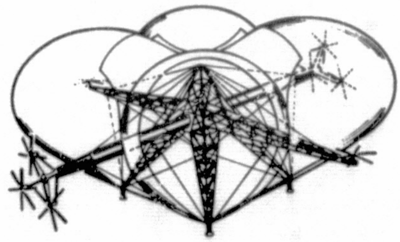
3) Piasecki Heli-Stat (Ref. 36)

The Heli-stat, makes use of existing helicopters to augment the buoyant lift of a rigid shell. A master control station in the aft, port helicopter is used to fly the helicopters, although standby pilots are aboard the other three aircraft. The control aspects of this concept are now being investigated by Piasecki Aircraft under USN contract.



4) Aerospatiale Atlas (Ref. 37)

This giant heavy lift concept is under devlopment using four large balloons 8.8 million ft^3 (250,000 m^3) each attached to an open frame tetrapod structure. Six 62' diameter SA-321 rotors provide propulsion with an additional pair for stabilization. A load of 500 tons is to be carried at speeds as high as 50 knots. (25.7 m/s)



A-3 REFERENCES

1. Wood, John E. R., The Aerospace Developments Concept, MIT FTL Report R75-2, January 1975

2. Mowforth, Edwin, The Airfloat HL Project, MIT FTL Report R-75-2, January 1975

3. Morse, Francis, Cargo Airships: A Renaissance?, Handling and Shipping, June 1972

4. Stinton, Darrol, A New Look at Airships, Flight International, 19 November 1970

5. Conrad, C. W., Conrad Airship Description, Conrad Airship Corporation, 1975

6. Kirschner, Edwin J., Russia's Nuclear Dirigibles, Popular Aviation, May/June 1967

7. Pavlecka, V. H. and Roda, John, State of the Art of Metalclad Airships, MIT FTL Report R-75-2, January 1975

8. Slate, Claude C. and Neumann, Richard D., The Slate All Metal Airship, MIT FTL Report R-75-2, January 1975

9. Joseph, James, Jet Powered Dirigibles, Science and Mechanics, January 1962

10. Anon., Das Schnelluftschiff ALV-C/1, Flugwelt, December 1971

11. Papst, Hermann, Method for Transporting Impellent Gases, MIT FTL Report R-75-2, January 1975

12. Papst, Hermann, Airship, U.S. Patent No. 3,456,903, 22 July 1969

13. Tucker, Curtis E. Jr., TX-1 Semi-Rigid Airship Programs, 1974

14, Balleyguier, M. Alain, A Practical Concept for Powered or Tethered Weight-Lifting LTA Vehicles, MIT FTL Report R-75-2, January 1975

15. Morisset, Jacques, La Renaissance des Dirigeables, Science at Connaissance, p. 866, 1974

16. Kleiner, H. J., Schneider, R., Duncan, J. L., The Design and Construction of the CAD-1 Airship, MIT FTL Report R-75-2, January 1975

17. Pohl, R. A., Two Lighter Than Air Systems in Opposing Flight Regimes, MIT FTL Report R-75-2, January 1975

18. Sonstegaard, Miles, Airships for Transporting Highly Volatile Commodities, MIT FTL Report R-75-2, January 1975

19. Sonstegaard, Miles, Transporting Gas by Airship, Mechanical Engineering, June 1973

20. Miller, Wm. M. Jr., The Dynairship, MIT FTL Report R-75-2, January 1975

21. Fitzpatrick, John R., et al, Airship, U.S. Patent No. 3,486,719, 30 December 1969

22. Mechanical Engineering Students, A New Vehicle Concept for Short Range Intercity Transport, Carnegie-Mellon University, 23 May 1968

23. Anon., Delphin-Luftschiff Ende Des Zeppilin?, Aero Magazine, July/August 1970

24. Davenport, A. C., The Variable Density Aircraft Concept, MIT FTL Report R-75-2, January 1975

25. Havill, C. Dewey and Harper, Michael, A Semi-Buoyant Vehicle for General Transportation Missions, MIT FTL Report R-75-2, January 1975

26. Anon., The Skyship Project, Aircraft Engineering, December 1974

27. Fitzpatrick, J. R., Lighter-Than-Air Craft, U.S. Patent No. 3,180,589, 27 April 1965

28. Anon., Three Hulled Airship, Air Progress, June/July 1964

29. Havill, C. Dewey and Williams, Louis J., Some Applications of Buoyancy Systems and Parawings to Replace Conventional and Proposed Transportation Systems, SAE Paper 720580

30. Fink, Donald E., Hybrid Heavy-Lift Vehicle Under Study, Aviation Week, 29 July 1974

31. Tinsley, Frank, Dirigible Cruise Ships, Mechanix Illustrated, December 1957

32. Anon., Parametric Study of Dynamic Lift Aerostats for Future Naval Missions, Goodyear Aerospace Corp. Report GER 13564, AD 833958, 31 January 1968

33. Alexander, Tom, A New Outbreak of Zeppelin Fever, Fortune, December 1975

34. Perkins, Russel G.,Jr. and Doolittle, Donald B., Aerocrane - A Hybrid LTA Aircraft for Aerial Crane Applications, MIT FTL Report R-75-2, January 1975

35. Anon., Du "Pegase" au "Titan", Aviation, 15 February 1974

36. Piasecki, Frank N., Ultra-Heavy Vertical Lift System - The Heli-Stat", MIT FTL Report R-75-2, January 1975

37. Anon., Vers une Nouvelle Generation de Dirigeables, Aviation, pg. 648, 15 February 1974

18 March 1975

APPENDIX B

FEASIBILITY STUDY OF MODERN AIRSHIPS

SOFT GOODS TECHNOLOGY REPORT

ILC DOVER
a division of ILC Industries Inc
DOVER, DELAWARE 19901

Prepared by:

Ralph W. Weis, Jr.
Ralph W. Weis, Jr.
Project Engineer
ILC Dover

John D. Scheible
John D. Scheible
Materials Engineer
ILC Dover

Approved by:

George P. Durney
George P. Durney
Balloon Program Manager
ILC Dover

Approved by:

Homer D. Reihm
Homer D. Reihm
Vice President, Engineering
ILC Dover

CONTENTS

Page No.

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Recent developments in modern materials technology along with a growing awareness of the need for energy conservation have provided the catalyst for a renewed emphasis on the study of lighter-than-air vehicles. The urgent need for such a relatively inexpensive and efficient carrier of personnel and bulk cargo has perhaps never been greater than it is today. Fortunately, as a result of the work accomplished during the past few years by a few modern pioneers, the materials technology necessary to proceed with this task is now available to us.

Because the soft goods subassembly or envelope of any LTA vehicle directly affects its payload capacity, it is economically very important to minimize its weight without sacrificing the strength or reliability of the vehicle. In addition, the structural integrity of the soft goods subassembly of any modern LTA vehicle is essential to mission success. The importance of proper fabric specification, precise patterning, and reliable fabric joining techniques are often underestimated or considered of minor significance relative to other aspects of the vehicle system. However, because of the unique loading characteristics of inflated structures and the sometimes complex behavior of intersecting surfaces of revolution, soft goods design technology is a very disciplined science encompassing design rules and evaluation techniques that must be followed to perform an effective and reliable design program. Regardless of LTA vehicle design, rigid or nonrigid, conventional or hybrid, envelope materials must be a major consideration in the design process because they have such a great influence on the ultimate success of the LTA vehicle.

2.0 MATERIALS

2.1 FABRICS

In materials constructions consisting of fabrics, coated with elastomers or laminated to films, the yarn from which the fabric is woven determines the basic mechanical properties of the construction. These properties include tensile strength, tensile modulus, and tear strength. Degradation due to flexing, abrasion, crease, and environmental exposure are also significantly effected by the yarn selection.

Cotton and rayon yarns which dominated early balloon fabric construction have been obsoleted by the introduction of high strength nylon and dacron yarns. In addition to higher strength to weight, both yarns exhibit improved resistance to abrasion, heat, chemicals and mildew attack. Equally important, they can be effectively coated, bonded and laminated to a large variety of materials to form continuous gas tight, exposure resistant constructions. Dacron yarns are generally preferred for their higher tensile modulus even though slightly lower in ultimate tensile strength.

A more recent development in yarns for high strength to weight applications are the Aramids of which DuPont's Kevlar 29™ is the most promising. Fabrics made from these yarns have a tensile strength of approximately three times that of dacron, with correspondingly higher tensile modulus. In these properties, the Kevlar 29 yarns are comparable to glass, but exhibit greater uniformity, lower density and much higher resistance to abrasion.

The premium cost and limited availability of Kevlar 29 has restricted its use to applications where strength to weight properties are critical. Its use is expanding rapidly, however, and is anticipated to continue to do so as demand fosters greater emphasis on development and production of this family of materials.

The properties of cotton, nylon, dacron and Kevlar 29 yarns as they apply to balloon fabric constructions are more specifically compared in Table 1 . At present, Dacron is preferred for construction when cost effectiveness and moderate performance are specified. Kevlar 29 is recommended in applications directed at expanding the state-of-the-art in aerostat and airship design and performance, and in those applications where cost related gains in efficiency of the total system are comparable to the increased cost of the fabric.

TABLE 1

MATERIAL PROPERTIES

	Tensile * (1000 PSI)	Elongation (%)	Tear (gm/mil) **	Density (gm/cc)	Max. Serv. Temp. °F-°C	Min. Serv. Temp. °F-°C	Abrasion Resist.	Weather Resist.	UV Resist.	Mildew Resist.	Flamm.
Fibers:											
Cotton	46-65	15-20		1.5	300 (149)		F	F	F	P	B
Nylon	67-86	26-32		1.14	350 (177)		G	G	F	G	SB
Dacron	77-138	13-14		1.38	350 (177)		G	G	G	G	SB
Kevlar 29	400	3		1.40	400 (204)		F	G	F	G	SE
Elastomers:											
Neoprene	3.0-4.0	550	FG	1.25	240 (116)	-40 (-40)	G	G	G	G	SE
Butyl	2.5-3.0	750	G	.90	300 (149)	-50 (-46)	G-E	G	G	F	B
Polyurethane	5.0+	650	E	1.25	240 (116)	-65 (-54)	E	G	G	F	SE
Hypalon	1.5-2.5	500	FG	1.2	325 (163)	-40 (-40)	E	E	F	E	SE
Viton	1.5-2.0	450	PF	1.4	500 (260)	-10 (-23)	G	E	F	E	SE
Natural Rubber	3.5-4.5	600	E	.93	180 (82)	-60 (-51)	E	F	F	P	B
Films:											
Mylar	20-35	130	15	1.39	250 (121)	-80 (-62)	E	E	F	E	SB-SE
Nylon	9-13	400	75	1.12	380 (193)	-100 (-73)	E	E	F	E	SE
Polyurethane	5-10	550	710	1.22	190 (88)	-100 (-73)	E	E	F	F	SB
Tedlar	7-18	250	100	1.5	225 (107)	-100 (-73)	E	E	E	E	SB-SE
Polyethylene	1.6-3.0	800	170	.92	180 (82)	-70 (-57)	E	E	P	E	SB
Teflon FEP	2.5-3.0	300	125	2.15	500 (260)	-425 (-254)	E	E	G	E	SF
Polyimine Kapton	25	70	8	1.42	730 (390)	-450 (-268)	E	E	E	E	SE

CODE:

E - Excellent
G - Good
F - Fair
P - Poor

B - Burn
SB - Slow Burn
SE - Self-Extinguishing
NF - Non-Flammable

*To convert tensile to Newtons/cm^2 multiply value in column bv 689.

**Elemendorf Tear

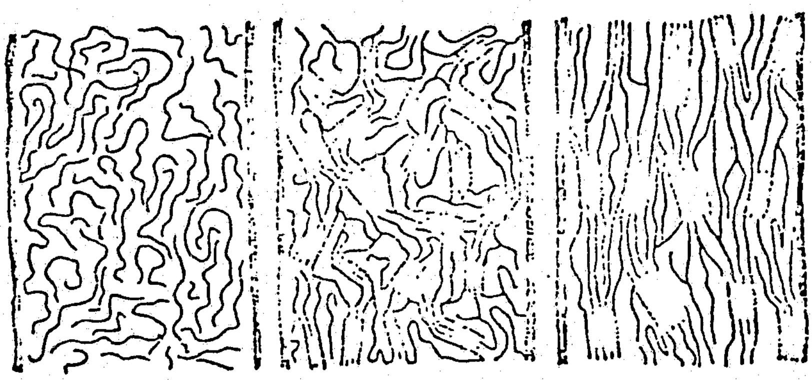
2.1.1 Yarn Construction

The absolute strength of individual yarns in a woven fabric has little meaning unless it is related to the size or density of the yarn. This convention is analogous to the custom of expressing the strength of most engineering materials in values of stress or force per unit area.

Yarn "stress" or tenacity is expressed in the units of grams per denier (gpd), with denier being an expression of yarn fineness. A one denier yarn is defined as weighing one gram per 9000 meters.

The tenacity of synthetic fibers is a material property that can often be altered or modified by treatment processes during or after manufacture. Of particular interest in structural fabric design is the inter-relation of a fiber's tenacity and elongation. In general, the higher the characteristic tenacity of a yarn, the lower its ultimate elongation. These variances are caused by a change in the physical structure of the extruded filament.

Figure 1 shows diagrams of fibers (a) with a low degree of crystallinity and orientation; (b) with a higher degree of crystallinity and a low degree of orientation; and (c) with a high degree of crystallinity and orientation. Crystallinity and orientation are accomplished by the combined effects of heat and mechanical stretching of the extruded filament. Temperature will critically influence the rate of crystal growth and their size, while stretching or "drawing" controls orientation.



Schematic representation of an amorphous polymer (a), a crystalline polymer (b), and an oriented crystalline polymer (c).

FIBER CRYSTALLINITY

Figure 1

When fibers become highly oriented through being stretched under controlled conditions, they usually acquire the properties, higher tenacity, lower elongation.

A higher degree of orientation results in a higher tenacity. This is the natural outcome of the stretching process in which the denier is very greatly reduced, whereas the breaking load is substantially unaffected. Table 2 illustrates the effect of orientation on the tenacity of fibers.

TABLE 2

EFFECT OF ORIENTATION OF FIBERS

Fiber	Orientation	Tenacity (gpd)	Elongation (%)
Kevlar 29	Extreme	22.0	3
Dacron, Type 68	High	9.2	13-14
Dacron, Type 55	Moderate	4.3	30

2.1.2 Yarn Candidates

Cotton

Early Aerostat materials were fabricated from readily available fabrics common to the textile industry. Most early balloon fabrics were made from cotton which was the most widely used material at the time. Efforts to provide a good helium barrier necessitated using natural rubber between the cotton plys and also as interior and exterior coatings. The low modulus and strength to weight ratio of the cotton base cloth and the rather large amount of rubber required to insure acceptable levels of helium permeability resulted in laminated blimp materials weight about 16-20 oz/yd^2 with tensile strengths on the order of 60 lb/in.

With the development of synthetic fibers exhibiting great improvements in strength to weight ratio, airship designers were ready to advance with the textile technology. Cotton substrate structural materials, having fulfilled an interim role in airship development, were quickly replaced by the synthetic materials.

Nylon

Nylon balloon materials were a great improvement over the original cotton fabrics. The nylons exhibited a much better characteristic strength and improved resistance to environmental degradation.

Biased nylon laminates were utilized by the Goodyear fleet during the Second World War and provided good functional non-rigid airship envelopes. Only because of the recent developments of modern materials have the nylons been replaced in their role as the "conventional" material substrate for airship fabrics.

Dacron Polyester

Dacron polyester yarns were initially developed about 1941. This new class of synthetic yarns was shown to exhibit equal strength to weight ratio, lower elongation and improved exposure resistance compared to the nylons. The polyesters can also exhibit great flexibility in physical properties as a result of specific manufacturing processes and treatments.

The tenacity and elongation at break of Dacron can be varied over a considerable range, according to the degree of drawing that is applied to the yarn. The higher the draw or stretch the higher the tenacity and the lower the elongation.

The stress-strain curve of Dacron polyester can be further altered by subsequent textile processing operations. For a higher modulus of elasticity and tensile the yarn may be hot-stretched and pre-shrunk. By proper manipulation of temperature, tension, strain (elongation) and relaxation, desired strength, elongation, and thermal shrinkage properties can be incorporated into hot-stretched, pre-shrunk yarns.

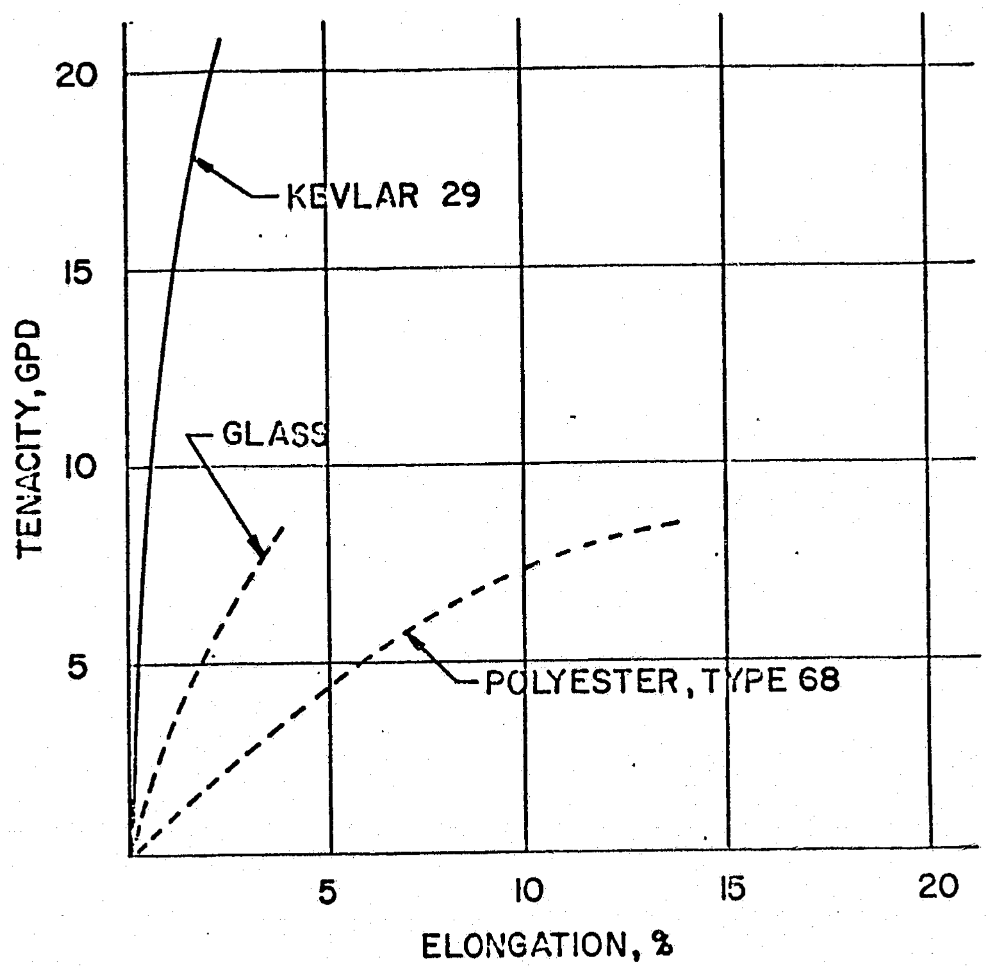
Kevlar

Great strides have recently been made in the development of new fibers available for fabrication of superior cloth. One such family of fibers, known as Aramids of which Kevlar 29 is a member, are presently available in deniers fine enough to make lightweight fabrics with excellent physical properties. Figure 2 illustrates the magnitude of difference between the stress-strain characteristics of high tenacity polyester, glass, and Aramid yarns.

Kevlar 29 has a non-linear curve in the same strength/ modulus range as glass fibers but shows significant advantages over glass in yarn strength uniformity, low density and resistance to surface damage and creep rupture under high stress. The stress-strain curve of Kevlar 29 can be further altered by subsequent textile processing operations to lower the modulus so that a functional end use soft goods item can be produced.

Figure 2

STRESS/STRAIN CHARACTERISTICS OF FIBERS



Unlike other organic yarns, Kevlar 29 demonstrates an increase in tenacity rather than a decrease when twist is applied.

Kevlar 29 yarns can be handled in all textile processes without difficulty. Knot strength is 37% and loop strength 50% of straight tensile strength. Retention of strength after conventional weaving is 90% of virgin yarn strength. The individual filaments of the yarn have a round cross-section and have a diameter of .47 mils. When pulled tight over an edge, they do not break sharply but bend while retaining high tensile strength.

Kevlar 29 fibers also have high thermal stability. When tested at 320° F in air, Kevlar 29 exhibits essentially zero shrinkage. When tested at 400° F, unprotected yarns evidence only 18% loss of physicals.

The unprotected fibers are also highly resistant to strong acids and bases, organic solvents, fuels, lubricants and hydraulic fluids. The ultraviolet light resistance of unprotected Kevlar 29 yarns is similar to nylon.

2.2 ELASTOMER COATINGS

A considerable variety of elastomer coatings have been used in the construction of aerostat and airship fabrics. They are used primarily to render fabric constructions impermeable to the inflation gas. A second function of elastomer coatings is to protect the fabric yarns from abrasion and degradation by handling and environmental exposure. They are also used to bond layers of fabric together and to join panels and reinforcements in assembly.

In practice, more than one elastomer is normally used with each having a prime function and a secondary function which compliments the other elastomers, and the fabric in the total system. In light weight constructions where static and dynamic stresses are low, or where weight is critical, one or two elastomers having a good balance of properties may be used. In heavier constructions, and when long service life is important, three or four elastomers may be used with each having a specific function.

Selection of the elastomers to be used in construction of a composite fabric becomes a trade-off study of the attributes of selected systems as they relate to the end use and performance requirements of the Aerostat. Table 1 provides a matrix for selection based on specific characteristics of the various elastomers. By weighing the values in the table according to priority in end use, preliminary selections can be made. In the final analysis, however, past performance, fabrication, and testing will establish those combinations which are most feasible in production, and provide the best all-around performance in specific applications.

2.3 PLASTIC FILMS

Plastic films have always had a prominent place in LTA systems due to their inherent high strength and low permeability compared to elastomeric coatings. Polyethylene film was used exclusively for early high altitude balloon experiments, and is still used extensively for this purpose. The relatively high permeability of this film, and inability to bond it to other materials, however, makes it unsuitable for advanced LTA systems.

The recent development of very thin films of significantly higher strength and very low permeability together with the technology for bonding these films to themselves, other films, and fabrics, has resulted in a totally new concept in LTA envelope constructions. Three films which have dominated recent development are polyester (Mylar), polyamide (Nylon, Capran) and polyurethane. Each of these possess unique characteristics applicable to LTA constructions. Of these, Mylar possesses the highest tensile strength and lowest permeability. It is also the most difficult to bond and possesses the least tear resistance. Nylon film, while significantly lower in tensile strength, has low permeability nearly equal to Mylar, is more readily bonded, and has good tear and abrasion resistance. Its useful temperature range is less than Mylar, but adequate for all but the most severe applications. Polyurethane films are significantly higher than Mylar or Nylon in permeability but are extremely tough and versatile in application. In fact, polyurethane films are superior to elastomeric coating in tensile strength, tear strength and abrasion resistance.

Mylar

Mylar, because of its high tensile and shear strength, and low permeability properties is used predominantly in either very thin unsupported film structures or as thin films laminated to light weight dacron and Kevlar scrims. Its application in laminated constructions is limited due to destructive shear forces which develop in the adhesive bond as film and fabric strength increases.

Nylon

Nylon films have similar application to that of Mylar with the lower modulus and improved bonding characteristics being more compatible to laminated structures. As such, they are most effective in the transition area between very light systems and the heavier multi-ply fabric structures.

Polyurethane

Polyurethane, because of its excellent physical properties, has been employed for a long time as a protective coating for single and multi-ply fabric structures. More recent development of thin case films of significantly lower permeability and even better physical properties has made it the most versatile of all materials in LTA soft goods construction. It not only is readily bonded to itself, but can be thermally bonded to a wide variety of fabrics and other films for economical continuous production of complex laminates.

A comparison of film and coating properties is shown in Table 1.

Tedlar

A fourth film, Tedlar, can not be compared in its physical properties to Mylar, nylon or polyurethane, but possesses the unique property of being totally resistant to ultraviolet (UV) radiation or other forms of natural aging. Not only is Tedlar totally resistant to UV radiation, but even in very thin films, it effectively blocks penetration of UV to underlying structures. It should suffice to note that in real time outdoor exposure tests, Tedlar has surpassed all other standards of evaluation.

Tedlar has been effectively laminated to most films and elastomers and should be considered for the exterior of any LTA system in which long service life is a requirement.

2.4 PHYSICAL PROPERTIES

2.4.1 Permeability

Low permeability to the lifting gas is a general requirement for the hull fabric and ballonets of non-rigid aerostats, and for the lifting bags and ballonets of rigid aerostats. An exception may be made for certain systems where hot air or steam are used as the lifting gas and controlled permeation is used with make-up provisions to maintain temperature. Low permeability would still be required if a closed system were employed.

The ligher gasses, notably hydrogen and helium, permeate materials many times faster than nitrogen, oxygen, or water vapor. Permeability to these gasses is therefore a principle factor in selecting a coating or film. In aerostats designed for long term continuous service, however, contamination of the lifting gas by the noted constituents of air is an important consideration. Because the difference in partial pressure of these constituents outside the aerostat is significantly higher than the total pressure difference of the aerostat, infusion and contamination will occur to the extent that the hull is permeable.

The specific permeability of elastomers varies significantly with the process by which the coatings of films are created. Heavily applied coatings are generally more permeable than coatings built up from repeated light applications, and these in turn are more permeable than extruded calendered coatings. In addition, the permeability of the basic elastomer will be increased or decreased depending on the type and quantity of additives commonly used in compounding to specific properties. The important result of this is that all permeability data is specific to the system tested and should be limited to general catagorization of elastomers in given applications.

Hydrogen and Helium

Hydrogen and Helium have similar permeation rates. Data sources are not consistent and often cite helium data actually based on hydrogen testing. Most data and theory supports higher permeability for helium based on the fact that it is monatomic and chemically inert. Table 3 lists helium permeability but makes no distinction relative to hydrogen.

No data was found on the change in helium permeability with temperature of the material but based on the results reported for air at elevated temperature, it might be expected to vary significantly with moderate changes in temperature.

Hot Air

A review of available data on permeability of elastomers to air at elevated temperatures shows a sharp increase between 75° F and 176° F for all but the most resistant compounds. The results were such that significant differences at 75° F tended to be minimized in the range of 175° F to 250° F. Selection of elastomers for this type of service would therefore be based on resistance to degradation of mechanical properties at the anticipated operating temperatures.

Steam

No data was found on permeability of elastomers or plastic films to steam. Data was found, however, on water vapor permeability at room temperature and on resistance of these materials to degradation on exposure to steam. It is recommended that materials selection for steam as a lifting gas be based on resistance to degradation as opposed to permeability.

Other Gasses

Other gasses, notably coal gas (Hydrogen, CO_2, and Methane) and ammonia have been used in balloons but no data was found relative to permeability. Future consideration of these or other materials should be accompanied by not only a test of permeability, but also tests to determine possible degrading effects on the barrier materials.

2.4.2 Mechanical Properties

Some of the basic mechanical properties of the common materials of LTA envelope constructions are discussed in the previous sections of this report. In these discussions, it may be noted that a proper balance of properties is more important than any single property. It may also be perceived that a specific property in one material can be sacrificed if a better overall balance of properties is achieved by allowing another

TABLE 3

MATERIALS PERMEABILITY
(Liters/M^2-MIL-24 Hrs-Atm.)

	Helium	Water* Vapor	Steam	Air 75°F (24°C)	Air 175°F (79°C)	Air 250°F (121°C)	Air 350°F (177°C)
Elastomers:							
Neoprene	26.0	G	F	3.9	42	115	310
Butyl	4.5	E	E	0.8	11	46	175
Polyurethane	10.0	F	P	2.0	40	126	290
Hypalon	P	E	G	26.0	27	86	232
Viton	G	E	G	G	G	G	G
Natural Rubber	93.0	F	P	17.0	F	P	P
Films:							
Mylar	1.5	1.8	G	.015			
Nylon	1.7	18.0	P	.015			
Polyurethane	2.0	45.0	P	0.6			
Tedlar	2.3	1.7	G	.004			
Polyethylene	43.0	1.5	P	P			
Teflon FEP	36.0	0.4	G	5.0			
Polyimide	3.9	5.4	G	.09			

*Note: Water vapor permeability data is in: (gm/100 in^2-24 hr.-Atm @ 25°C)

CODE: E - Excellent
G - Good
F - Fair
P - Poor

material to satisfy that property requirement. For example, the tensile strength, tear and abrasion resistance of an elastomer or film with the primary function of a gas barrier is only important to the extent that it is not supported and protected from stress by a structural fabric.

The following paragraphs discuss in more detail the pertinent mechanical properties of materials as they relate to LTA envelope construction.

Tensile Properties

The tensile properties of ultimate strength and elongation and modulus can be considered collectively. It is imperative that the primary structural material, whether it be film or fabric, be of sufficiently high modulus to prevent significant stress in ancillary materials. Its ultimate strength and elongation provide a measure of the extent to which local load concentrations due to irregularities in patterning and seaming and attachments can be tolerated.

The tensile properties of the coatings or films supported by the structural material determine in a large part how well they resist flexing and creasing where very high local elongations are possible. These materials should therefore be characterized as tough and elastic.

In some light weight systems a film and scrim may share the structural load. In this instance it is important that the tensile properties be carefully matched.

Tear Strength

The relative tear strength of materials of similar tensile properties depends on the ability of the material to distribute the tearing stress. In films and elastomers, it is related to crystallinity and alignment of shear planes in the molecular structure. In fabrics, it is the size of the individual yarns and their ability to slip so as to share the tearing stress.

The tear strength of elastomers can be modified to some degree by the selection of compound additives. Plastic films are less flexible, and in the case of Mylar, which has poor tear strength, a tear resistant reinforcement is normally required.

Fabrics vary significantly in tear strength depending on yarn size, strength, and ultimate elongation. They also vary as a result of the type and tightness of weave. In tear, each yarn tends to load and fail individually in sequence. Fabrics of similar weight and tensile strength may consist of a large number of small yarns or fewer larger yarns. The fabric constructed

of the larger, stronger yarns will have a significantly higher tear strength.

Less apparent is the fact that a loosely woven fabric in which the yarns can slip and bunch up will have a higher tear strength than a heavier fabric of the same yarn size where slip is restricted. Conversely, anything that tends to keep yarns from slipping, specifically coatings, will reduce the tear strength. This is the primary reason why strikethrough, or penetration of surface coatings into the intersticies of a fabric, is avoided as much as possible.

Numerous weave constructions such as basket weaves and twills, in which two or more yarns are woven more or less as one, also have higher tear strength than plain weaves; i.e., one over, one under, etc.

One weave designed to stop tear propagation, appropriately called Rip-Stop weave, consists of a doubled or heavier yarn inserted at intervals in the weave.

One of the advantages of bias plied fabrics in addition to increased stability is the placing of multiple yarns in the tear plane and the high resistance of fabrics to tear in a bias direction. This characteristic is carried over to triax fabrics, reference Paragraph 3.3, and as would be expected is enhanced by a relatively loose coupling of the yarns by low modulus bonding systems in the plied fabrics.

Flex and Crease Resistance

Materials designed to withstand stresses imposed from normal static and dynamic working loads can still fail if creased or repeatedly flexed beyond their normal working range. When creased or bent sharply on itself severe tensile stresses are induced in the outer skin of the material. These stresses, if they do not produce immediate failure, will over a period of time cause leakage and failure as a result of radically accelerated aging. In addition, multiple ply structures are subjected to high shear loads which tend to delaminate the materials.

Repeated flexing has two potentially damaging effects; one, many elastomers, films, and yarn filaments tend to work-harden and become brittle as a result of repeated flexing; second, fabric yarn filaments abraid on each other causing progressive weakening of the fabric.

For the above reasons, tests have been developed to evaluate flex and crease resistance and are an important consideration in material selection. Parameters of evaluation include both structural properties and permeability.

Abrasion Resistance

Abrasion can occur from a number of sources. Wind driven dust and rain will abraid the surface of an LTA envelope. Contact with lines and other suspension systems cause abrasion. Normally fixed attachments can move and abraid with hull flexing. Last, but not least, ground handling of deflated systems causes abrasion. All of these factors require that all exposed surfaces be resistant to abrasion. When exposed construction materials lack abrasion resistance some form of coating or cover must be provided.

2.4.3 Environmental Resistance

In addition to mechanical stresses, LTA envelope materials will be subjected to potentially degrading effects of exposure to atmospheric temperature extremes, sunlight, moisture and salt spray. Systems which use hot air or steam will be exposed to very high temperatures. In addition, atmospheres peculiar to some end uses, fuels, and fuel combustion products can have a degrading effect on LTA envelopes. Each of these must be anticipated and considered in material selections. Many accelerated test methods have been developed to evaluate these effects on materials. It must be demonstrated by data analysis and/or test that the materials retain their physical properties within established design limits throughout their projected service life.

3.0 MATERIAL CONSTRUCTION

Rigid airship envelope materials are light weight coverings which serve primarily to provide a smooth aerodynamic shape and prevent environmental degradation of the airship system. These materials are usually well supported by the rigid skeleton and do not experience the severe loading stresses normally encountered by a non-rigid hull material. Anticipated aerodynamic loading conditions are used to size the strength requirements of rigid envelopes. These envelopes can be fabricated with single ply biaxial fabrics which are coated to provide the needed environmental protection.

Non-rigid airship envelope materials are structural fabrics which are designed to accomplish two basic functions in a pressure-rigidized structure; 1) support the internal and external structural loads, and 2) contain and protect the pressurizing medium. The primary material structural properties associated with the first function are tensile strength, tear strength, and bias strength or dimensional stability. The importance of good tensile and tear properties is obvious; however, one might not readily appreciate the significance of dimensional stability.

A large inflatable structure is required to withstand severe loading which is often imparted in a direction other than along one of the two principal axes of a conventional biaxial fabric. Under such loading the perpendicular yarn intersections of a biaxial fabric would tend to shift and the yarn pattern would change from rectangles to diamonds. These single ply biaxial fabrics coated with an impermeable elastomer are sometimes suitable for small aerostat applications where external loading is minimal. Larger inflated structures, such as the envelope of a modern non-rigid LTA vehicle, require envelope materials which exhibit good dimensional stability and will not experience this bias distortion under severe loading conditions encountered in service. Several methods of designing such materials are discussed below.

3.1 MULTIPLE PLY COATED FABRICS

Bias Ply

One method which is used to stabilize the rectangular geometry of a biaxial fabric is to bond two layers of orthogonal fabrics together with one on the bias. In this construction an impermeable elastomer film is used between the base fabric and a second stabilizing ply which has its warp and fill yarns oriented 45° from those of the base fabric. The elastomer serves as a gas barrier and also as a bonding agent to secure the two plys.

A final coating is then applied to each side of this laminate. Often an elastomer highly impermeable to the intended

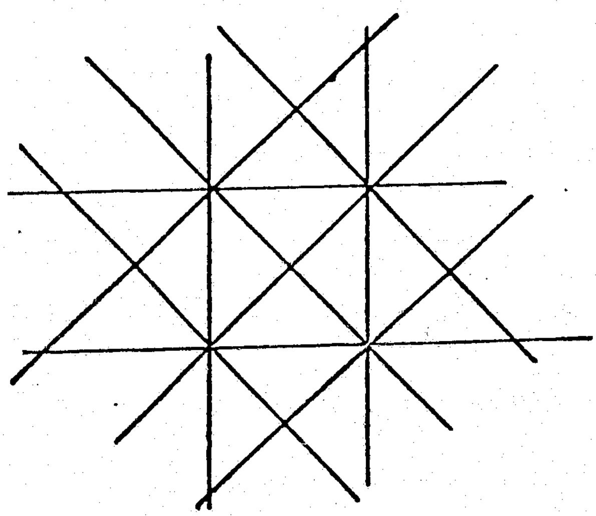
lifting gas is used for the center layer, while a tough durable elastomer with good abrasion and envrionmental resistance is used for the outer coatings.

The dimensional stability or shear stiffness afforded by the biasing operation can be illustrated by Table 4 showing shear stiffness of several fabrics both before and after biasing. Figure 3 illustrates the yarn orientation of a two ply biased material

TABLE 4

SHEAR STIFFNESS BEFORE AND AFTER BIASING

Fabric	Before Biasing	After Biasing w/ 1.1 oz/yd^2 (37.3 gm/m^2) at 45°)
2.1 oz/yd^2 (71.2 gm/m^2)	23 lbs. (102 n.)	82 lbs. (364 n.)
3.25 oz/yd^2 (110.2 gm/m^2)	32 lbs. (142 n.)	99 lbs. (440 n.)



ORDERLY YARN ORIENTATION OF BIASED ORTHOGONAL FABRICS

Figure 3

Spunbonded

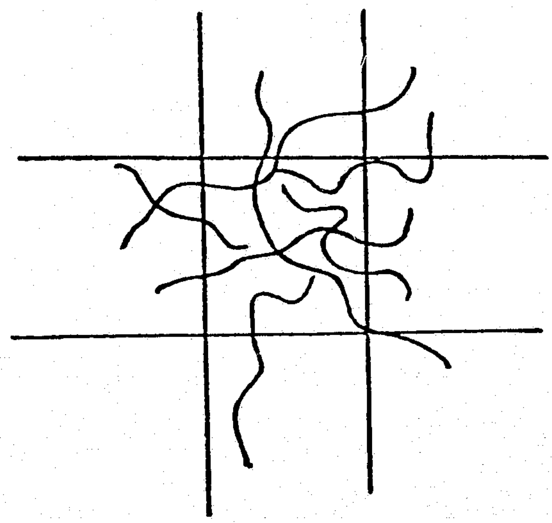
A second method which can be utilized to dimensionally stabilize the structural fabric is to ply a spunbonded fabric, rather than an orthogonal fabric, to the structure fabric.

Spunbonded is a generic term coined to differentiate it from other textile materials. Spunbonded fabric is a sheet structure made with continuous filaments which are formed into a sheet or web and then bonded into position.

The filaments are bonded together at the crosspoints and these bonds hold the fibers together in the sheet-like structure. This provides a uniform appearance and good cover or hiding power coupled with high porosity. Microphotographs of the structure reveal that they are fine webs of randomly arranged continuous filament fibers. Use of this type of fabric affords high tear and tensile strength.

Random fiber arrangement gives the structure its isotropic nature.

The distinctive characteristics of spunbonded fabrics include high tensile strength, optimal fiber orientation, outstanding tear strength and toughness, and excellent dimensional stability. The advantage of utilizing spunbonded fabrics in place of very light weight orthogonal fabric to dimensionally stabilize the structural fabric is that no biasing operation is necessary. Figure 4 illustrates this construction. The advantage of no biasing realizes a savings in cost and laminating time and requires fabrication of only a single fabric, that is, no left or right hand bias.



RANDOM YARN ORIENTATION OF SPUNBONDED RE-INFORCED FABRICS

Figure 4

Experimental measurements of shear stiffness of two-ply fabrics using spunbonded materials are illustrated in Table 5.

TABLE 5

SHEAR STIFFNESS BEFORE AND AFTER TWO-PLYING USING SPUNBONDED FABRIC

Fabric	Before Plying	After Plying to 2.1 oz/yd^2 (71.2 gm/m^2) Base Fabric
Reemay 2011	12 lbs. (53 n.)	62 lbs. (276 n.)
Reemay 2014	15 lbs. (67 n.)	64 lbs. (284 n.)
2.1 oz/yd^2 (71.2 gm/m^2) base fabric alone	23 lbs. (102 n.)	

3.2 SINGLE PLY WITH FILM

Another material construction which can be used to increase the dimensional stability of an orthogonal base fabric involves the lamination of an unsupported high modulus film to the base substrate. In this construction, the high modulus film is analogous to the bias ply previously described and must lock the fabrics rectangular weave geometry and prohibit yarn course slippage or distortion. In this construction the film provides a tensile member in the bias direction.

The effectiveness of a film reinforced orthogonal fabric is very dependent upon the ply adhesion between the substrates. If this adhesion is low, ply separation occurs and results in an unstable fabric. Tests run on sample materials using this stabilizing technique have indicated that several layers of high modulus film are required to achieve a marked improvement in a fabric's resistance to bias distortion. These results are shown in Table 6.

Other Reinforced Films

The basic concept of laminating a conventional biaxial base fabric to a high modulus film was extended in an effort to improve bias strength and stability. Although this research was conducted on materials sized for free balloon applications, it is mentioned here to illustrate the importance of bias strength and the effects of bias reinforcement on the behavior of a composite balloon material.

This bias reinforced material was produced on a machine called a Flying Thread Loom (FTL). In this process a high modulus film was used as a base. As the film passed through the FTL, individual yarns impregnated with a polyester adhesive were laminated to the film at various angles. Three basic yarn directions were used simultaneously to

yield a triangular reinforcement pattern. Experiments were conducted on several yarn orientation systems and it was found that the most favorable configuration was with the yarns 60° apart such that an equilateral triangle pattern was formed.

TABLE 6

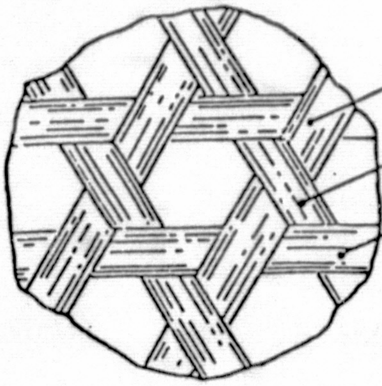
SHEAR STIFFNESS OF BIAXIALLY REINFORCED FILMS

Construction	Before Laminating	After Laminating
Dacron Scrim 13 x 13 Count (Resin Impregnated) Laminated to 1 Mil Tedlar	36 lbs. (160 n.)	36 lbs. (160 n.)
Dacron Scrim 13 x 13 Count (Resin Impregnated) Laminated to .5 Mil Mylar	36 lbs. (160 n.)	36 lbs. (160 n.)
Dacron Scrim 13 x 13 Count (Resin Impregnated) Laminated to 2 Layers of .25 Mil Mylar and 1 layer 1.0 Mil Tedlar	36 lbs. (160 n.)	89 lbs. (396 n.)
Kevlar Leno Scrim 5 x 5 Mesh (Laminated with 1.0 Mil Tedlar Film)	4 lbs. (18 n.)	25 lbs. (111 n.)

The results of the preliminary testing of this construction provided encouraging results. Although these materials were very open weaves (only 1 to 4 yarns/inch) and were not sized for application in large pressured airships, the results of these preliminary tests indicated that multiple yarn systems could provide significant improvements in the dimensional stability of balloon materials.

3.3 SINGLE PLY COATED, TRIAXIAL

Triaxial fabric is a woven fabric configuration consisting of three yarn systems with individual yarn courses oriented 60° apart as illustrated in Figure 5.



TRIAXIALLY REINFORCED FABRIC

Figure 5

Unlike the FTL three axis fabric described above the triaxially woven fabric does not require adhesion to a high modulus film to maintain yarn orientation. This material utilizes a triangular interlocking of the three yarn systems to provide material body such that the fabric can be rolled and handled much like conventional biaxial fabrics. This base fabric can then be coated on both sides with a polymer or polymers to provide the gas retention and environmental barriers necessary for a functional LTA material.

The most interesting aspect of this triaxial construction is that no second operation such as bias ply or high modulus film lamination is necessary to provide bias strength and stability. The coated substrate, by its own construction geometry, exhibits the dimensional stability necessary for a stable structural fabric.

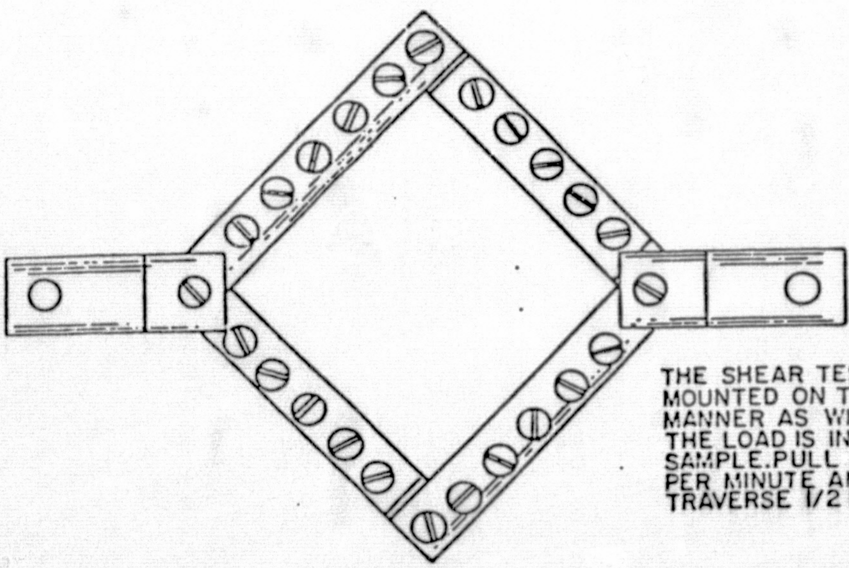
Table 7 illustrates a comparison of the shear resistance of a coated triaxially woven fabric to that of two other candidate constructions.

TABLE 7

DIMENSIONAL FABRIC STABILITY *

Fabric Geometry	Weight Oz/Yd^2 (gm/m^2)	Breaking Strength Lb/In (n/cm)	Shear Resistance Lbs. (n.)
Two-Ply Biased Fabric Construction, (1.1 oz/yd^2 Biased at 45° to the 3.25 oz/yd^2 Fabric)	10.85 (368)	160 x 160 x 120 (280 x 280 x 210)	99 (440)
Biaxially Reinforced Film Construction (4 oz/yd^2 Laminated to 2 Layers .25 MIL Mylar and 1 Mil Tedlar)	8.5 (288	200 x 200 x 90 (350 x 350 x 158)	89 (395)
Triaxially Reinforced Film Construction (1.5 oz/yd^2 Urethane Laminated)	5.0 (170)	150 x 150 x 150 (263 x 263 x 263)	> 240 >(1067)

*NOTE: This data was obtained using the apparatus and procedure shown below.



THE SHEAR TEST FIXTURE SHALL BE MOUNTED ON THE INSTRON IN SUCH A MANNER AS WHEN THE TEST BEGINS, THE LOAD IS INSTANTLY APPLIED TO THE SAMPLE. PULL SPEED SHALL BE .5 INCHES PER MINUTE AND THE SAMPLE SHALL TRAVERSE 1/2 INCH.

FABRIC SHEAR TESTER

4.0 FABRICATION TECHNIQUES

Modern soft goods fabrication procedures utilize several different techniques to join envelope material panels as well as load spreaders, catenary curtains, and other soft goods interface assemblies. Normally several different methods are used on a single assembly, the correlation of technique to application being based primarily on reliability, manufacturing versatility and production cost trade-offs.

4.1 SEWING

Numerous types of sewing machines are available with multiple needle heads or special feed and folding assemblies for use on large production items such as the LTA soft goods sub-assembly. Stitching would normally be confined to uncoated components or components which do not serve as direct gas barriers. Catenary curtains, load patch reinforcement webbings, and loop tape tie down assemblies are typical soft goods assemblies which would utilize various sewing techniques.

Often, if a sewn seam must be made on a direct gas barrier or through a coated material which could result in direct leakage or wicking through the substrate fabric yarns, a light weight tape can be cemented over the seam to prevent loss of the buoyant fluid. This tape is sometimes a coated fabric, but since it must carry no structural loads is often an unsupported film of a relatively impermeable material.

4.2 CEMENT BONDING

Cement bonding of seams is a very important manufacturing capability. Usually much slower than automated heat sealing processes, cemented seams are often necessary on final assembly where the component parts are too large to be readily accessible by sealing machines.

The many specialized adhesive systems available today enable such cemented seams to exhibit excellent reliability and resistance to extreme environmental conditions. The capability of using a fast drying solvent based cement on the envelope of LTA vehicles will enhance field operations and field repair of the ships. Minor rips, tears and holes in the envelope can be readily repaired without requiring unscheduled vehicle "downtime" for envelope panel replacements. The envelope can be field patched to continue its mission and the damaged panel replaced during the next scheduled service appointment.

4.3 THERMAL SEALING

One type of heat induced polymer joining is simple thermal impulse sealing. In this technique a hot bar, die, or roller

is made to apply pressure to the seam area. The heat is resistance generated and passes through a heated bar and through the seam by normal conduction. Adjacent layers of polymer on the overlapped panel edges or on seam tapes are then fused together.

4.4 DIELECTRIC (RF) SEALING

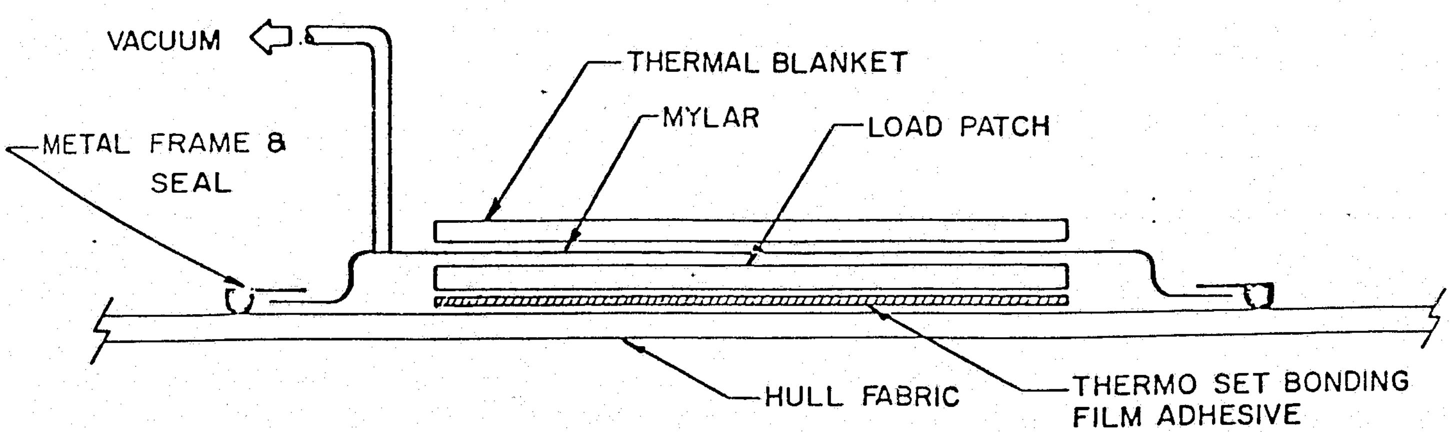
This process utilizes the electrical properties of polymer which are moderately polar in nature. The dielectric heat is caused by the work (dielectric loss) produced using an alternating electric field at a relatively high frequency which results in a heat build-up at the interface. A seal is accomplished by placing two similar films between two matched sealing dies and activating the high frequency current for a specific dwell time. Sufficient pressure is applied to the dies to force the two layers of film together so that the interfaces come into intimate contact.

The greatest advantage in dielectric heat-sealing is the control of the system and the repeatability of results. This sealing process will form a bond between fabrics which is greater than the strength of the fabric.

4.5 THERMAL ADHESIVE BONDING

The thermal adhesive bonding technique utilizes a heat-activated film adhesive to effect a bond between two fabrics. The film is used in conjunction with a vacuum frame and a thermal heating blanket which provide uniform pressure and heat to the bonding area.

This process is ideally suited to sealing load patches in place on aerostat envelope. A sketch of this apparatus is shown below



LOAD PATCH ATTACHMENT METHOD

Figure 6

4.6 ULTRASONIC SEALING

Another unique joining technique is ultrasonic sealing. In this process two materials are passed through a machine which has opposing rollers which can be smooth or patterned, and are caused to vibrate at ultrasonic frequencies. This vibration and pressure is transmitted to materials passed between the rollers and provide the intimate contact between faying surfaces needed to produce a seal.

4.7 TYPICAL SEAMS

Two basic seams are shown in Figures 7 and 8. The first is a lap seal in which normal stresses on the seal of the first two films are in a shear mode. The strength of the seams is affected by the seal beads which are formed at the outer edges of the seal. Pinked tapes are used on one side of the modified lap seam to prevent the formation of a straight line material modulus jump which would create a high stress line and a potentially low tear edge.

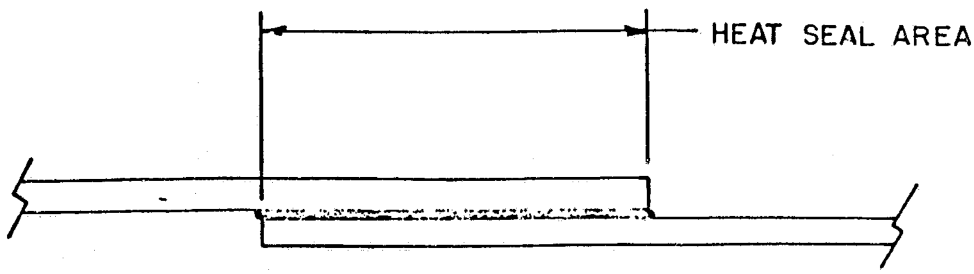
A cross sectional view of four panels joined in this manner is illustrated in Figures 9 and 10.

Irrespective of the bonding method used, it is necessary that the joined surfaces be of adequate dimensions to insure that shear stresses at the interface do not exceed the bond strength of the bonded coatings to the substrate.

4.8 CONCLUSIONS AND RECOMMENDATIONS

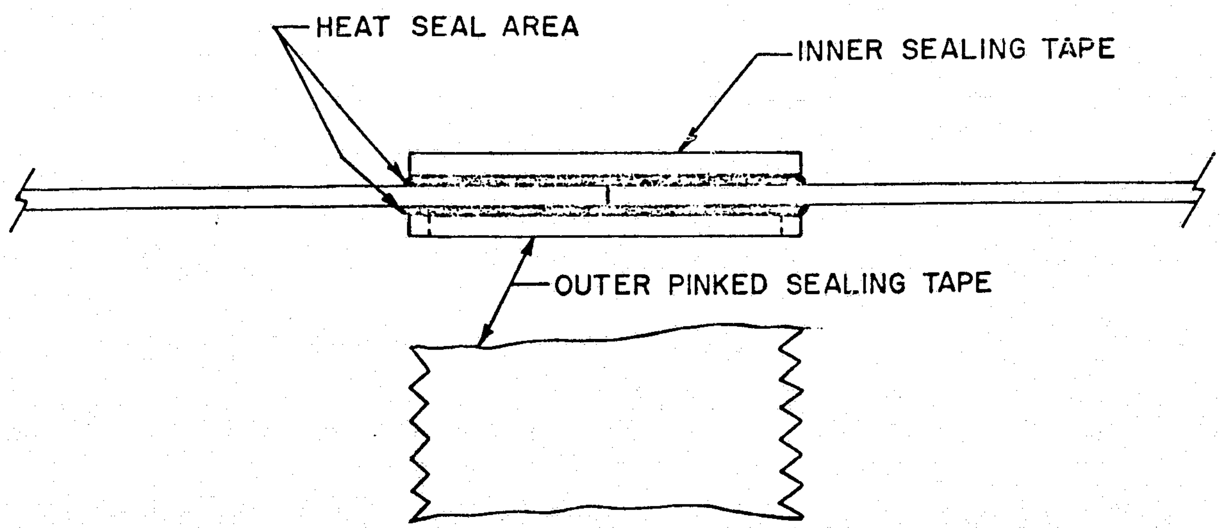
Based on previous experiences with each of these fabrication techniques it is recommended that dielectric sealing be utilized wherever possible in joining soft goods panels together. Dielectric sealing techniques are very reliable; there is a minimum of heat buildup in the sealing dies during repetitive operation; and the process is much faster than cementing or sewing and overtapeing. It is also possible to incorporate filler strips of film adhesive into dielectrically sealed seams if required by the particular coating polymer.

Also, a recent innovation in dielectric sealing technology involving the use of thermal sensitive dies on sealing tapes has made it possible to visually inspect every foot of seam to insure that the seal was made within a prescribed temperature range. This practice has greatly advanced the reliability of dielectrically sealed seams and at the same time greatly simplified the quality assurance function of such manufacturing operations.



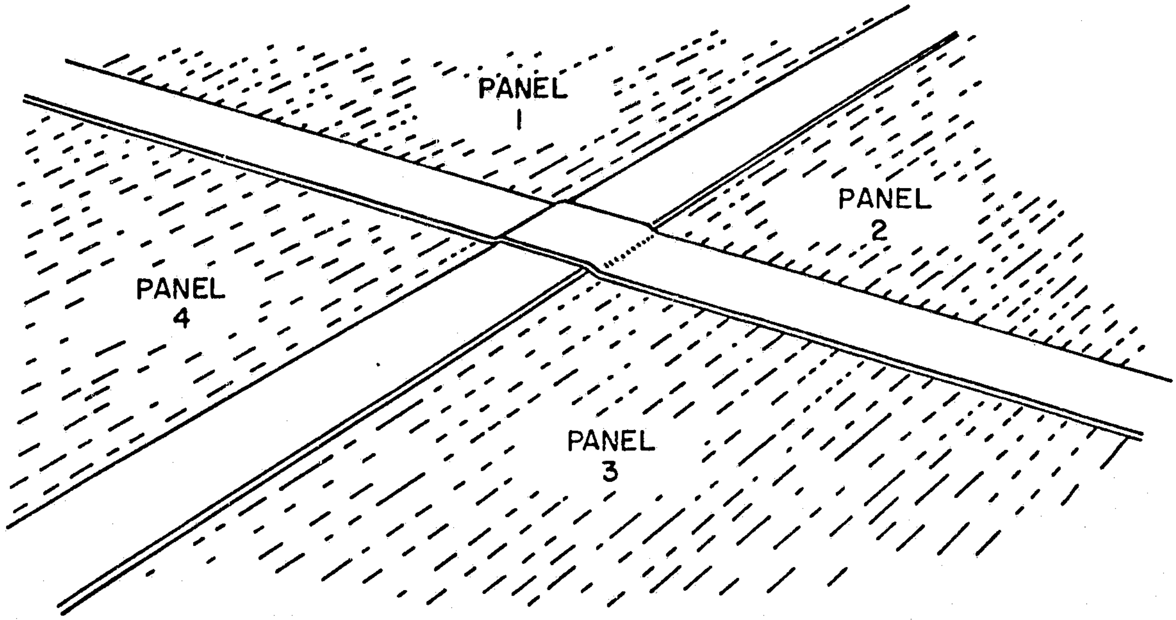
BASIC HEAT-SEAL LAP SEAM

Figure 7



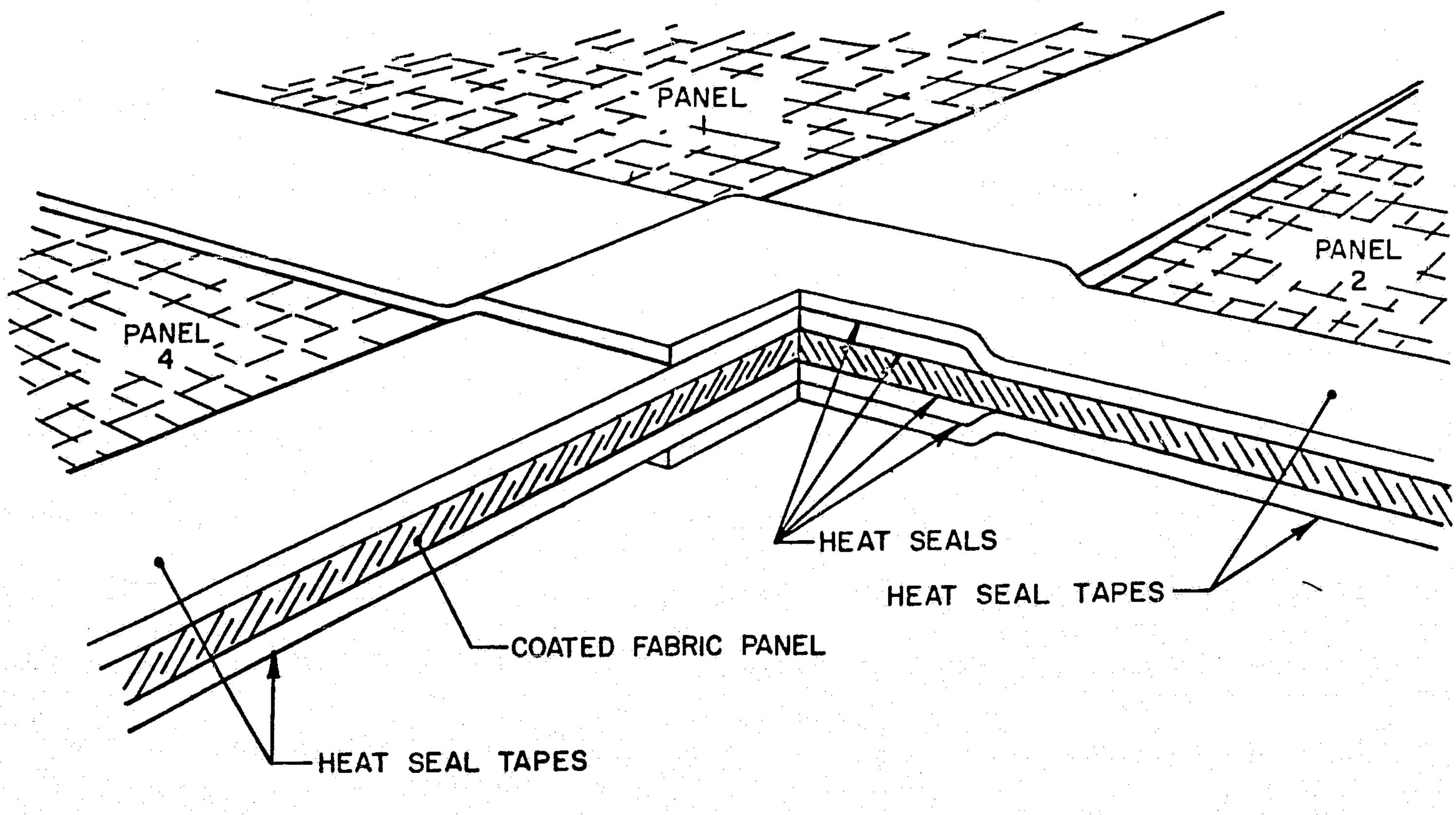
MODIFIED HEAT-SEAL LAP SEAM

Figure 8



PANEL AND SEAM CONSTRUCTION

Figure 9



METHOD FOR JOINING FOUR
PANELS BY HEAT-SEALING

TYPICAL HEAT SEAL INTERSECTION

Figure 10

5.0 SOFT GOODS DESIGN TECHNOLOGY

Modern soft goods design technology will have a significant impact on the success of any detailed LTA system design. The soft goods designer will assume responsibility for final materials selection, fabrication procedure, interface with frame or other components, and internal gas bag design and suspension. Some of these tasks will require trade-off analyses between conventional materials or methods while others may involve advancements in the state-of-the-art in soft goods technology.

For example, the most significant limitation on the practical design of large non-rigids will be the capability to provide reliable seaming techniques for modern high strength structural fabrics. Present fabric joining methods utilize sealing or cementing configurations in which the laminated shear strength of the coating polymer is required to transmit the fabric stresses. The advanced, new high-strength fabrics will soon reach the practical limitations of this technology. It will then be necessary to relieve the coating polymer from the load carrying function and effect more reliable yarn to yarn junctions. For example, specially prepared material panels with the edges left uncoated for cement bonding is a potential solution.

Soft goods materials technology will provide active development functions in an LTA system design. Modern "super films" capable of providing up to 20 years protection from ultraviolet and environmental degradation are now becoming available and should be examined in composite envelope material configuration. During an LTA development program such samples would be subjected to numerous cycle and aging tests as well as incorporated into existing balloon systems for actual flight aging data.

Soft goods interface with structural frame members, control cabins, or other "hard" components will involve a significant design effort. The primary factors in such a task would be attachment reliability, load distribution, panel maintenance, and manufacturing versatility. It is anticipated that panel attachment to frame members will be made with an edge capture assembly of some type.

One aspect of a rigid LTA system where drastic improvement can be made over the conventional rigids of the past is gas bag design and orientation as well as internal netting design. The projected weight of a modern gas cell is about one-half of the old conventional cells. Also, new high strength Kevlar cords should provide an excellent, lightweight, flexible gas netting material. Jacketed or polymer impregnated cord would provide a smooth surface for gas bag contact and also would prevent fraying or abrasion of the Kevlar filaments.

6.0 CANDIDATE MATERIALS

The development of specific materials for application to LTA construction must consider many factors. The first consideration must be the tensile stresses to which the material will be exposed. These can be accurately predicted from a static stress analysis of the end configuration and from dynamic analysis and wind tunnel tests on model structures. The hull fabric analysis must consider what part the material plays in the total structure. In non-rigid LTA's, the hull fabric provides all of the structural support and also serves as a permeability barrier. In rigid or semi-rigid LTA's, the hull fabric plays a lesser roll and may only be required to withstand local dynamic wind loadings. In both cases, the overall size and performance; i.e., speed and maneuvering requirements are prime factors in determining the structural requirements.

In Section 4.0 it was explained that rigid envelopes, which are well supported by the airship's framework are good candidates for single ply biaxial fabric construction. Non-rigid envelopes, however, require a much different material to accommodate the loading characteristics they must encounter.

Each of the material constructions described in Section 4.0 is a candidate non-rigid envelope material. It is apparent from past experience that each has specific characteristics which make it a good envelope material construction, but at the same time some other properties which might make it less attractive.

Final specification of an envelope material must be based on a comprehensive evaluation of the specific application for which it is intended. A materials development trade-off would be required in which all properties of the candidate materials could be compared and evaluated.

For the purposes of providing meaningful weight and cost data for the various LTA vehicle candidates, it is necessary to establish base line materials. Based on a trade-off evaluation which considered physical properties in addition to manufacturing versatility, field repairability, and long term life, a set of candidate base line materials has been established.

6.1 HULL MATERIALS

After determining the structural requirements of the hull fabric, including adequate safety factors for reliability and long life, the structural material strength requirements can be specified. At the present

time, two-ply biased fabrics, film reinforced fabrics, and coated triaxial fabrics are all potential non-rigid envelope materials. Based upon an overall evaluation of properties such as permeability and long term life with no flex fatigue coupled with its excellent physical properties and low weight, a coated triaxially woven fabric is considered to be an excellent candidate material construction for non-rigid envelopes.

In selection of coatings for hull fabrics, service life and service environment are prime considerations. In non-rigid LTA's, permeability to the lifting gas is an equally important consideration. Ease of application of the coatings to the fabric and to themselves or other coatings, must also be considered.

Polyurethane is rapidly evolving as the most versatile and reliable of currently available coatings in providing an optimum balance of the above properties. Its mechanical properties are unexcelled, and its permeability and weather resistance can be effectively augmented when required by application of a thin film of Tedlar.

Tables 8 and 9 list candidate materials of the two constructions described above for rigid and non-rigid envelopes. Projected weight and strength data have been included for both dacron polyester and Kevlar 29 yarns and are plotted in Figures 11 and 12. It is apparent from the curves that a significant weight savings can be realized with Kevlar. This savings will be of great significance when it is realized as additional payload capacity of the system.

6.2 BALLONET MATERIALS

Non-rigid LTA's employ air cells called ballonets to maintain the LTA shape (pressure) and for static balance and trim. These cells are formed by diaphragms within the LTA hull which are not subjected to external structural loading but must be of adequate strength and resiliance to withstand significant inertial forces associated with the mass properties of the contained air. In addition, low permeability to the lifting gas is essential.

The mechanical stresses on the ballonet material can be calculated based on their size and shape and on the inertial forces resulting from LTA maneuvers. While significant, these forces are less than those normally imposed on the hull and permit lighter constructions. The ballonets are seldom fully inflated, however, and must be highly resistant to continuous flexing. For this application, and in the absence of requirements for high stability, single ply biaxial dacron structural fabrics are more suitable than they would be in the hull. Light weight Kevlar biax and triax fabrics still offer advantages where weight is critical.

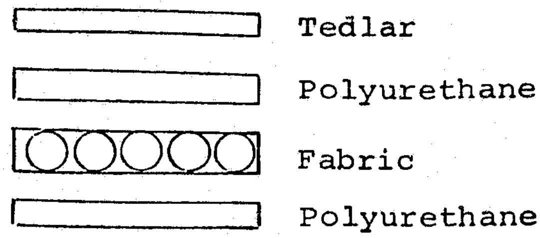
The lower tensile requirements of the ballonets and greater emphasis on flex resistance results in the gas barrier coating playing a greater roll in structural design of the material. Urethane again is an outstanding choice in coating selection. Its elastomeric properties and abrasion resistance are specifically suited to long flex life.

6.3 LIFTING GAS CELLS

Rigid LTA's normally employ a number of impermeable bags which contain the lifting gas. They are characteristically captured by and transmit lift to the LTA through a system of nets and lines to the rigid structure. In this manner, structural loads on the cell fabric is minimized. Since the size and shape of the cells is controlled by the restraint system, the cell material can be standardized to make optimum use of available fabrics and coating. Abrasion, flex resistance and impermeability are the prime requisites. Structural films such as mylar, nylon, polyurethane films are all candidates for this application. Mylar is outstanding in tensile properties and requires minimum fabric reinforcement. Its poor tear propication resistance and limited bonding potential, however, somewhat offset its advantages. Nylon films have much greater tear resistance and are readily bonded, however, in adequate thickness to be comparable to Mylar in permeability, they tend to be stiff and less manageable. Polyurethane is only slightly more permeable than nylon but retains its elastomeric properties better. Based on overall performance and ease of bonding, it is a prime candidate.

TABLE 8

BIAXIAL CONSTRUCTION CANDIDATES



Kevlar 29

Tensile (lb/in)	Weight (oz/yd^2)				
	Urethane	Fabric	Urethane	Tedlar	Total
188	1.0	1.0	1.0	1.0	4.0
262	1.0	1.4	1.0	1.0	4.4
310	1.0	1.6	1.0	1.0	4.6
438	1.5	2.3	1.0	1.0	5.8
524	2.0	2.8	1.0	1.0	6.8
621	2.5	3.3	1.5	1.0	8.3

Polyester

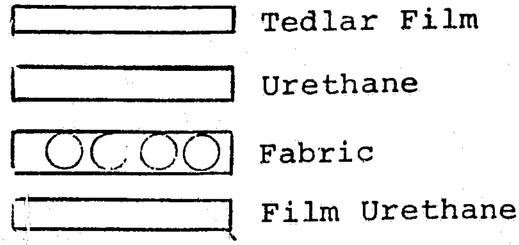
Tensile (lb/in)	Weight (oz/yd^2)				
	Urethane	Fabric	Urethane	Tedlar	Total
122	1.0	1.8	1.0	1.0	4.8
173	1.5	2.5	1.0	1.0	6.0
207	1.5	3.0	1.0	1.0	6.5
216	1.5	3.2	1.5	1.0	7.2
244	2.0	3.6	1.5	1.0	8.1
292	2.5	4.3	1.5	1.0	9.3
462	3.5	6.8	2.0	1.0	13.3

NOTE: It is anticipated that the minimum weight shown in the table represents the lightest composite weight that can readily be manufactured and handled using normal equipment and processes.

Conversion factors: 1 oz/yd^2 = 33.91 gm/m^2
1 lb/in = 1.75 n/cm

TABLE 9

TRIAXIAL CONSTRUCTION CANDIDATES



Kevlar 29

Count*	Yarn**	Tensile (lb/in)	Weight (oz/yd²) Film Urethane	Fabric	Urethane	Tedlar Film	Total
18.5 x 3	140/1	105	1.5	1.0	1.0	1.0	4.5
18.5 x 3	200/1	150	1.5	1.5	1.0	1.0	5.0
18.5 x 3	400/1	370	2.0	3.1	1.4	1.0	7.5
18.5 x 3	400/2	740	2.0	6.2	1.8	1.0	11.0
18.5 x 3	400/3	1100	2.5	9.3	2.2	1.0	15.0
18.5 x 3	1000/2	1850	4.0	15.4	3.6	1.0	24.0
10.0 x 3	1500/3	2250	4.2	18.8	4.0	1.0	28.0
10.0 x 3	1500/4	3000	6.0	25.0	4.5	1.0	36.5
18.5 x 3	1500/3	4150	7.0	34.7	5.3	1.0	48.0

Dacron Polyester

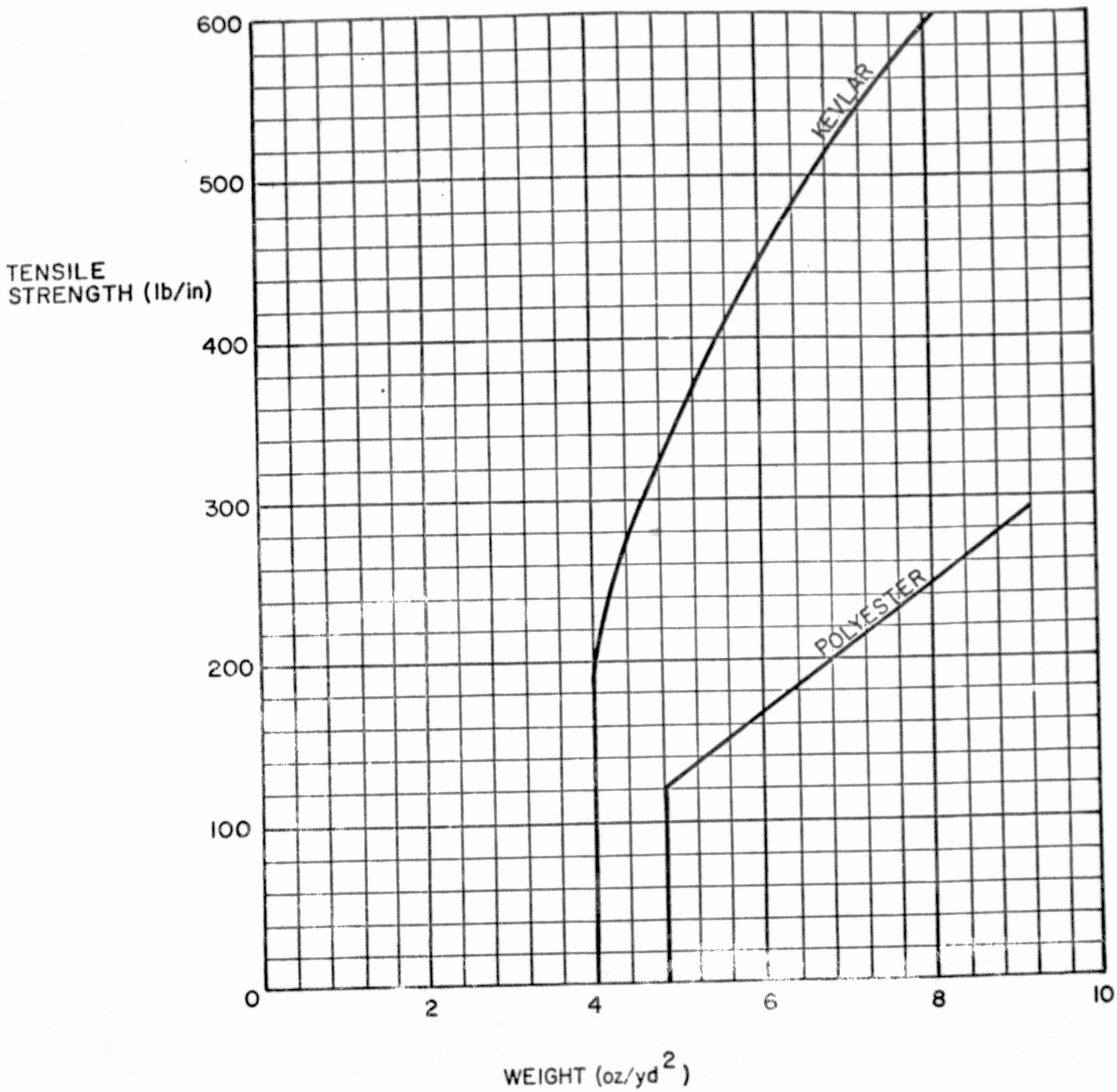
Count*	Yarn**	Tensile (lb/in)	Weight (oz/yd²) Film Urethane	Fabric	Urethane	Tedlar Film	Total
18.5 x 3	200/1	65	1.5	1.5	1.0	1.0	5.0
18.5 x 3	400/1	130	2.0	3.1	1.4	1.0	7.5
18.5 x 3	400/2	260	2.0	6.2	1.8	1.0	11.0
18.5 x 3	400/3	390	2.5	9.3	2.2	1.0	15.0
18.5 x 3	1000/2	650	4.0	15.4	3.6	1.0	24.0
10.0 x 3	1500/3	790	4.2	18.8	4.0	1.0	28.0

* ends per inch x # of axes
** yarn denier/# of plies

NOTE: It is anticipated that the minimum weight shown in the table represents the lightest composite weight that can readily be manufactured and handled using normal equipment and processes.

Conversion factors: 1 oz/yd^2 = 33.91 gm/m^2
1 lb/in = 1.75 n/cm

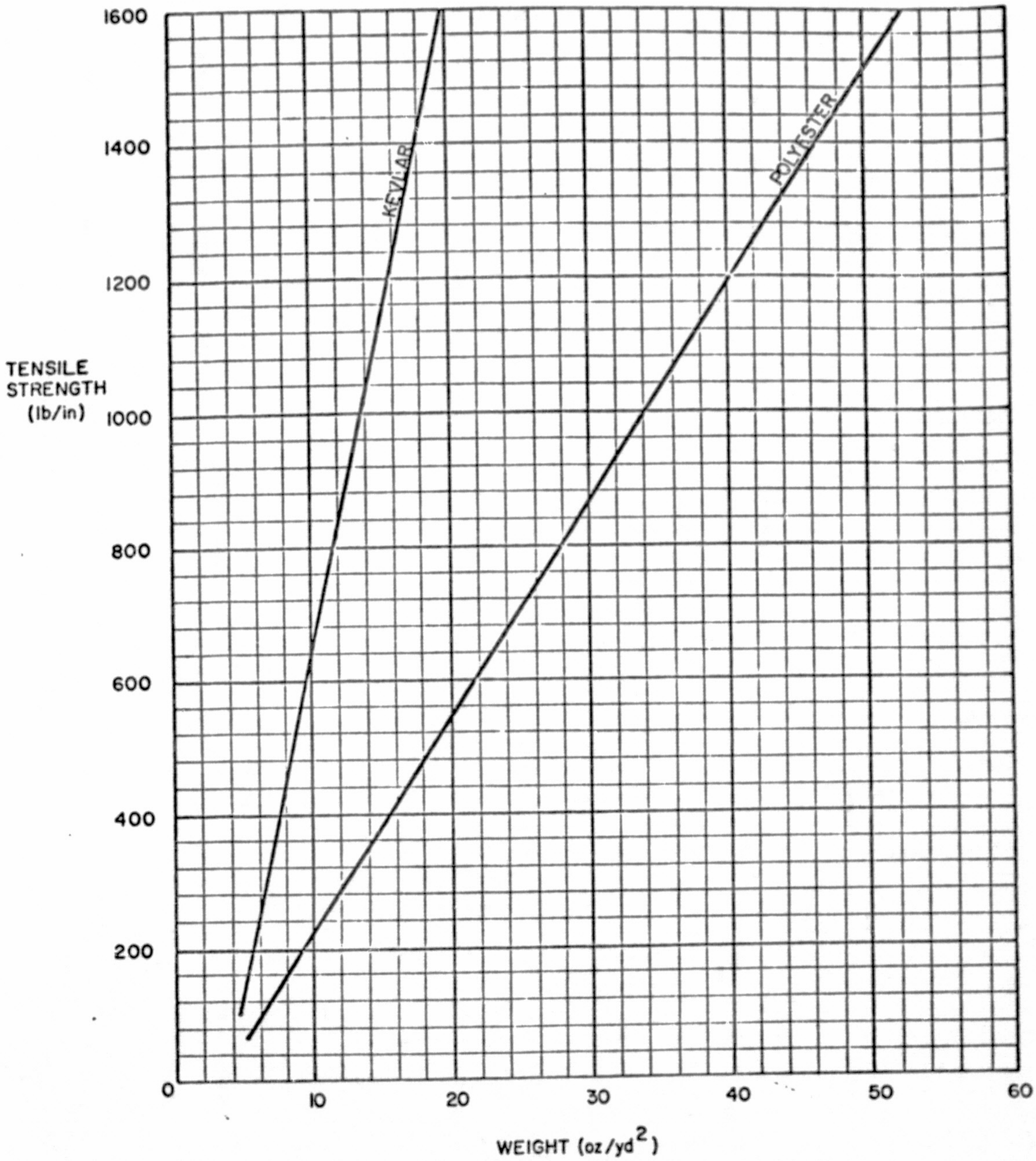
BIAXIAL CONSTRUCTION CANDIDATES



Conversion factors: 1 oz/yd^2 = 33.91 gm/m^2
1 lb/in = 1.75 n/cm

Figure 11

TRIAXIAL CONSTRUCTION CANDIDATES



Conversion factors: 1 oz/yd^2 = 33.91 gm/m^2
1 lb/in = 1.75 n/cm

Figure 12

7.0 AIRSHIP WEIGHT ANALYSIS

The weight of the soft goods subassembly including, where applicable, ballonets, gas bags, catenary curtains, seam tapes, and panel attachment assemblies has been estimated for each of six preliminary candidate LTA vehicle concepts. This estimate considered three flight cruise velocities and utilized individual fabric panel sizing constraints consistent with past experience and projected vehicle structural specifications.

The first section simply establishes the maximum dynamic pressure loading condition as a function of cruise velocity. Table 10 lists the results of the weight estimate process for each of six configurations:

1. Conventional non-rigid
2. Conventional rigid
3. Megalifter
4. Heli-Stat
5. Helipsoid
6. Dynairship

Following Table 10 the engineering guidelines and specification which were assumed for the analysis are described in detail.

Dynamic Pressure Loading

maximum altitude = 10,000 feet

maximum velocity = 50, 100, 200 knots

The most severe pressure loading will be at low altitude, high velocity.

at sea level ρ_{AIR} = .002378 slug/ft^3

Velocity conversions

50 knots	=	84.45 ft/sec
100 knots	=	168.90 ft/sec
200 knots	=	337.80 ft/sec

$$q_f = \frac{1}{2}\rho V^2$$

Max q_{50} = 8.48 lb/ft^2 = 1.63 I.W.G. (inches of water gage)

Max q_{100} = 33.92 lb/ft^2 = 6.52 I.W.G.

Max q_{200} = 135.68 lb/ft^2 = 26.08 I.W.G.

$$q_f = 3.392 \times 10^{-3} V^2$$

where q_f = free stream q in lb/ft^2

V = velocity in knots

TABLE 10A

SOFT GOODS WEIGHT ESTIMATES
(ENGLISH SYSTEM)

Airship	Velocity (knots)	W_H (hull weight) (lbs)	W (gas cells or ballonet weight) (lbs)
Conventional Non-Rigid	50 100 200	$W_H = S_{WET}\ (1.552 \times 10^{-3}\ D + .274)$ $W_H = S_{WET}\ (4.792 \times 10^{-3}\ D + .274)$ $W_H = S_{WET}\ (1.776 \times 10^{-2}\ D + .274)$	$W_{ballonet} = .15\ S_{WET}$
Conventional Rigid	50 100 200	$W_H = .276\ S_{WET}$ $W_H = .276\ S_{WET}$ $W_H = .331\ S_{WET}$	W gas cells $= .358\ S_{WET} + .894\ D_{max}^2$
Megalifter	50 100 200	$W_H = .276\ S_{WET}$ $W_H = .276\ S_{WET}$ $W_H = .331\ S_{WET}$	W gas cells $= .358\ S_{WET} + .894\ D_{max}^2$
Heli-Stat	50 100 200	$W_H = .276\ S_{WET}$ $W_H = .276\ S_{WET}$ $W_H = .331\ S_{WET}$	W gas cells $= .358\ S_{WET} + .894\ D_{max}^2$
Helipsoid	50 100 200	$W_H = .276\ S_{WET}$ $W_H = .276\ S_{WET}$ $W_H = .331\ S_{WET}$	W gas cells $= .358\ S_{WET} + .125\ S^2$
Dynairship	50 100 200	$W_H = .276\ S_{WET}$ $W_H = .276\ S_{WET}$ $W_H = .331\ S_{WET}$	W gas cells $= .358\ S_{WET} + .113\ S^2$

S_{WET}: hull surface area (yd^2)
D : maximum hull diameter (ft)
S : maximum hull width (ft)

NOTE: Gas cell netting for the rigid configurations could be made from 1/8 inch diameter Kevlar cord weighing 5#/K ft with a tensile strength of 1000 lbs. Assuming a 1.5 ft. grid pattern, this material would weigh about 1.0 oz/yd^2.

TABLE 10B

SOFT GOODS WEIGHT ESTIMATES (INTERNATIONAL SYSTEM)

Airship	Velocity (m/sec)	W_H (hull weight) (Kg)	W (gas cells or ballonet weight) (Kg)
Conventional Non Rigid	25.7 51.5 103.0	$W_H = S_{WET}(2.762 \times 10^{-3} D + .149)$ $W_H = S_{WET}(8.527 \times 10^{-3} D + .149)$ $W_H = S_{WET}(3.160 \times 10^{-2} D + .149)$	W ballonet = $.081\ S_{WET}$
Conventional Rigid	25.7 51.5 103.0	$W_H = .150\ S_{WET}$ $W_H = .150\ S_{WET}$ $W_H = .179\ S_{WET}$	W gas cells = $.194\ S_{WET} + 4.355\ D_{max}^2$
Megalifter	25.7 51.5 103.0	$W_H = .150\ S_{WET}$ $W_H = .150\ S_{WET}$ $W_H = .179\ S_{WET}$	W gas cells = $.194\ S_{WET} + 4.355\ D_{max}^2$
Heli-Stat	25.7 51.5 103.0	$W_H = .150\ S_{WET}$ $W_H = .150\ S_{WET}$ $W_H = .179\ S_{WET}$	W gas cells = $.194\ S_{WET} + 4.355\ D_{max}^2$
Helipsoid	25.7 51.5 103.0	$W_H = .150\ S_{WET}$ $W_H = .150\ S_{WET}$ $W_H = .179\ S_{WET}$	W gas cells = $.194\ S_{WET} + .609\ S^2$
Dynairship	25.7 51.5 103.0	$W_H = .150\ S_{WET}$ $W_H = .150\ S_{WET}$ $W_H = .179\ S_{WET}$	W gas cells = $.194\ S_{WET} + .550\ S^2$

S_{WET}: hull surface area (m^2)
D : maximum hull diameter (m)
S : maximum hull width (m)

NOTE: Gas cell netting for the rigid configurations could be made from 3.18 mm diameter Kevlar cord weighing 7.4 Kg/1000 m with a tensile strength of 4445 n. Assuming a .46 m grid pattern, this material would weigh about 33.91 gm/m^2.

Conventional Non-rigid

σ_p = maximum stress due to internal pressure

$\sigma_p = P\, R_{max}$

Assume: - airships will all have hard cone to take a large portion of frontal q loading.

- envelope is exposed to q loading at a point just behind the rigid nose cone.
- q component normal to surface at that point q ($\perp$) is equal to less than .2 q_f.
- internal pressure, P, should be about .5 IWG (2.601 lb/ft^2) above maximum + q ($\perp$) at all times to prevent envelope dimpling.
- maximum anticipated negative pressure in high lift region is on the order of - .5 q_f.
- envelope material should be sized to withstand .2 q_f + .5 IWG internal pressure stress plus - .5 q_f external aerodynamic pressure or a total effective internal pressure of (.7q_f + 2.601) lb/ft^2

$$P = (.7q_f + 2.601)\ \text{lb/ft}^2$$

$$= [\ (.7)\ (3.392 \times 10^{-3}\ V^2) + 2.601\ ]\ \text{lb/ft}^2$$

$$P = (2.374 \times 10^{-3}\ V^2 + 2.601)\ \text{lb/ft}^2$$

$$R_{max} = \frac{D_{max}}{2} = .5D\ \text{ft}$$

$$\sigma_p = (2.374 \times 10^{-3}\ V^2 + 2.601)\ (.5D)\ (\tfrac{1}{12})$$

$$= (9.892 \times 10^{-5}\ V^2 + .108)\ D\ \text{lb/in}$$

Thus for: 50 knots σ_p = .3553 D lb/in

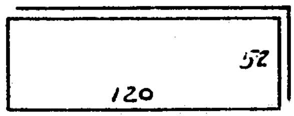
100 knots σ_p = 1.097 D lb/in

200 knots σ_p = 4.065 D lb/in

Weight factors

In order to include the weights of other soft goods items associated with the envelope, an effort has been made to establish an area factor which can be applied to the envelope weight relationship.

Seam tapes: A typical fabric panel size of 120 inches x 52 inches is assumed and seams are assumed to have 4 inch tapes each side.

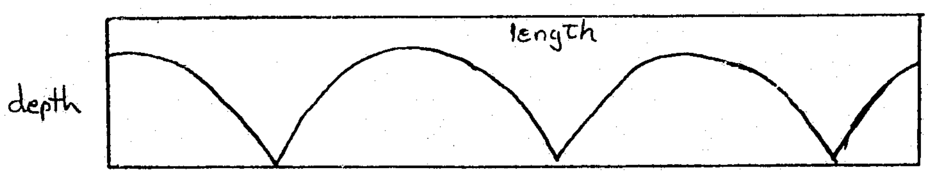


The effective specific area of the fabric in this panel is then greater than the panel surface area by a factor of:

$$\frac{60 \times 128}{52 \times 120} = \frac{7680}{6240} = 1.231$$

This indicates that the seams in a non-rigid would increase the normal specific surface area or S_{WET} by 23.1%.

Internal catenaries: Passenger or cargo bay configuration is not defined, however, for a ballpark weight estimate, it will be assumed that 4 catenary lines are required for internal support.



Typical fabric usage including base strip for each catenary = .5 (length x width)

Considering the $57 \times 10^3\ ft^3$ ship for sizing coefficients:

$$\text{length} \approx .75\,(130)\left(\frac{V}{57{,}000}\right)^{1/3}$$

$$= 2.534\ V^{1/3}$$

$$\text{depth} \approx 3\left(\frac{V}{57{,}000}\right)^{1/3}$$

$$= .078\ V^{1/3}$$

$$\text{fabric usage} = .5\ [2.534\ \forall^{1/3} \times .078\ \forall^{1/3}]$$

$$= .0988\ \forall^{2/3}$$

Now this can be related to specific fabric weight by numerically examining one of the non-rigid ships.

Consider the 57,000 cubic foot size:

$$\text{the catenary usage would be} = 4\ (.0988)\ (57{,}000)^{2/3}$$

$$= 65.0\ yd^2$$

This ship would also require about 1040 yds^2 of envelope material. The catenary material would affect the overall effective material weight by $\frac{1040 + 65.}{1040.} = 1.063$ or by 6.3%

Thus, by considering catenaries and seams it is apparent that the effective fabric surface area would be 23.1 + 6.3 = 29.4% greater than the normal S_{WET}. When constructing the envelope weight vs D relationship for the conventional non-rigid this factor is utilized.

Ballonet for conventional non-rigid

1. Normal single ballonet similar to Family II series (30%) has an area of about A = 890 yd^2.

2. Assume that we will split ballonet in two and make a fore and aft ballonet to help trim capabilities. It will be assumed that the two extra end caps will increase the area by 25%.

3. Similar to hull analysis, it will be assumed that tapes will increase the area by 23%.

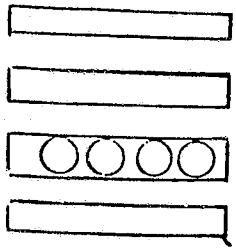
4. Effective ballonet surface area A = (1 + .25 + .23) 890 for Family II ballonet = 1317 yd^2

5. This represents $\frac{1317}{2200} = .60\ S_{WET}$ with respect to hull surface area and will be used for the non-rigid analysis.

$$\text{Eff}\ A_{ballonet} = .60\ S_{WET}$$

Candidate material specifications - Non-rigids

Hull:



from material weight vs. strength curve:

$$\dot{w} = .0108\,\sigma_m + 3.388$$

where σ_m is in lb/in

$\dot{w}$ is in oz/yd^2

$\overline{W}_H$ (Weight of hull soft goods) $= \dot{w}\,(E_{ff}\,S_{WET})$

$$E_{ff}\,S_{WET} = 1.294\,S_{WET}$$

Thus: $\overline{W}_H = 1.294\,w\,S_{WET}\,\left(\frac{1}{16}\right)$

$$= .0809\,S_{WET}\,(\dot{w})$$

$$= .0809\,S_{WET}\,(.0108\,\sigma_m + 3.388)$$

Utilizing the values of fabric stress as a function of hull diameter established for each cruise velocity along with a safety factor of 5, the soft goods weight estimates can be given.

For 50 knots: $\overline{W}_H = .0809\,S_{WET}[(.0108\ (5)\ (.3553)D + 3.388]$*

$$\overline{W}_H = S_{WET}\,(1.552 \times 10^{-3}\,D + .274)$$

where $\overline{W}_H$ is in lb.

S_{WET} is in yd^2

D is in feet

For 100 knots: $\overline{W}_H = .0809\,S_{WET}\,[.0108\ (5)\ (1.097)D + 3.388]$*

$$\overline{W}_H = S_{WET}\,(4.792 \times 10^{-3}\,D + .274)$$

For 200 knots: $\overline{W}_H = .0809\,S_{WET}\,[.0108\ (5)\ (4.065)D + 3.388]$*

$$\overline{W}_H = S_{WET}\,(1.776 \times 10^{-2}\,D + .274)$$

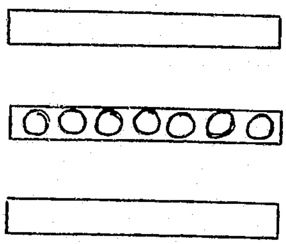
* Due to the minimum weight of about 4.5 oz/yd^2 for this construction, the bracketed quantities should be $\geq$ 4.5 for all cases.

Comments: -Due to the high dynamic pressure experienced at 200 knots and the correspondingly high internal gas pressure required, the effectiveness of a non-rigid configuration is probably limited to a maximum velocity in the order of 100 knots.

-Also, based on a maximum fabric strength seaming capability of 1000 lb/in the non-rigid airship size range should be limited to a diameter of about 180 feet for the 100 knot case.

Ballonet: Low strength requirement in any size ship since it acts only as a diaphragm.

Will consider the following construction:



2.0 oz/yd^2 coat film urethane (polyether)

1.0 oz/yd^2 biaxial Kevlar 29 fabric *

$\underline{1.0}$ oz/yd^2 urethane (polyether)

4.0 oz/yd^2 total

$$\overline{W}_B = w\,(E_{ff}\, A_{ballonet})$$

$$= 4.0\ \text{oz/yd}^2 \left(\frac{1}{16}\right) .60\ S_{WET}$$

$$= .15\ S_{WET}$$

where $\overline{W}_B$ = ballonet weight in lbs.

S_{WET} = hull surface area in yd^2

* Low denier ($\approx$ 50 denier) Kevlar yarns will be available in late 1975 making lightweight materials such as these quite feasible.

Hull - Past experience with rigid airships has indicated a longitudinal beam spacing of about 12 feet to be a good rule of thumb. A maximum spacing of 12 feet will be assumed; it will be smaller if necessitated by fabric load limitations at the high velocity condition.

- Assumed deflection of panel is 1/20 of longitudinal girder separation.

- Airships will have hard nose cone to take high q loading at nose.

- Dynamic pressure loading over entire ship is assumed to vary between + $.2q_f$ and - $.2q_f$.

- It should be noted that these assumed loading factors are engineering estimates based on wind tunnel data of typical airship configuration. Factor specification in a more comprehensive design effort will be based on wind tunnel tests of the exact configuration under study.

- It is assumed that diagonal shear wires between adjacent longitudinal girders will be placed in such a way to provide transverse support and anti-flutter attachment points.

Fabric tension: $t = \frac{pC^2}{8h}$

where p = pressure loading = .2 qf

C = longitudinal girder separation

h = fabric or panel deflection = $\frac{1}{20} C$

t = 2.5 pC

Velocity = 50 knots q = 8.48 lb/ft^2

$t = 2.5(.2)(8.48)(12) = 50.9$ lb/ft = 4.2 lb/in

Velocity = 100 knots q = 33.92 lb/ft^2

$t = 2.5(.2)(33.92)(12) = 203.5$ lb/ft = 17.0 lb/in

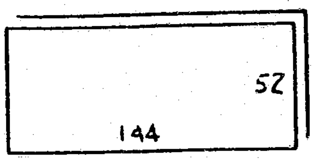
Velocity = 200 knots q = 135.68 lb/ft^2

$t = 2.5(.2)(135.68)(12) = 814.1$ lb/ft = 67.8 lb/in

Effective material specific weight on rigids:

- Assume fabric is run with warp along longitudinal direction of ship.
- In order to joint fabric strips, attach panels to girders, and provide anti-flutter attachments, it will be assumed that the typical panel size is 52" wide by 12 feet long.
- The edges of such a panel will be attached to neighboring panels or to an attachment assembly such as a T-tape or loop tape.

Effective specific weight for each panel will be approximated by assuming two 2.0 inch strips on each side.



$$\frac{56 \times 148}{52 \times 144} = \frac{8288}{7488} = 1.107$$

<u>Gas Bags</u>

In order to provide redundancy and also because of typical main transverse frame support wiring, there are generally 12 to 20 gas cells in a conventional rigid airship.

In this analysis 16 cells will be assumed. The material required will be $S_{WET} + 30\,\bar{A}$ where $\bar{A}$ is the average cross sectional area of the airship in yd^2.

Since there is typically a large cylindrical center section or nearly cylindrical section in conventional rigid airships, the average cross sectional area is very nearly equal to the major cross section.

$$\bar{A} \approx .95\pi \left(\frac{D\ max}{2}\right)^2 \left(\frac{1}{9}\right) = .0829\ D\ max^2$$

Gas bags are also typically sized about 3% larger and 1.5% larger in circumference than the space they occupy.

$$\therefore\ \bar{\bar{A}} \approx (S_{WET} + 30\ (.0829\ D\ max^2)\quad (1.03)\ (1.015)$$

$$\bar{\bar{A}} = 1.045\ S_{WET} + 2.60\quad D\ max^2$$

Gas bag seams: Assume 1.5 inch tape each side every 52" along circumference.

$$\frac{55 \text{ x circumference}}{52 \text{ x circumference}} = 1.058$$

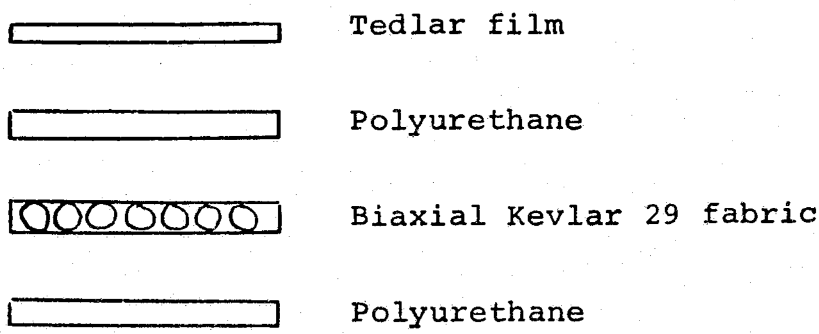
Gas bag patches and orientation assembly: assume additional 10%

$$\text{Effective Area} = (1 + .058 + .10)\ [1.045\ S_{WET} + 2.60\ D\ max^2]$$

$$A_{Eff} = 1.21\ S_{WET} + 3.01\ D\ max^2$$

Candidate material specification - conventional rigid

Skin:



This material construction has a minimum specific weight of about 4.0 oz/yd^2 based on the necessary coating required for environmental protection and environmental versatility.

Now the strength requirements (with a safety factor of 5) can be given for each cruise velocity considered.

at 50 knots:	$t = 4.2 \times 5 = 21.0$ lb/in	$\dot{w}_{50} = 4.0$ oz/yd^2
at 100 knots:	$t = 17.0 \times 5 = 85.0$ lb/in	$\dot{w}_{100} = 4.0$ oz/yd^2
at 200 knots:	$t = 67.8 \times 5 = 339.0$ lb/in	$\dot{w}_{200} = 4.8$ oz/yd^2

$\overline{W}_H$ (Total weight of hull covering including seams) $= 1.107\ S_{WET}\ (\dot{w})\ (\frac{1}{16})$

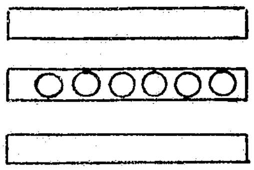
$= .069\ S_{WET}\ \dot{w}$

at 50 knots $\quad \overline{W}_H = .276\ S_{WET}$

at 100 knots $\quad \overline{W}_H = .276\ S_{WET}$

at 200 knots $\quad \overline{W}_H = .331\ S_{WET}$

Gas Cells - reinforced polyether polyurethane



2.00 oz/yd^2 film polyether polyurethane

1.00 oz/yd^2 non-woven or light weight biaxial

1.75 oz/yd^2 film polyether polyurethane

4.75 oz/yd^2

$$\bar{W}_{Gas\ Cell} = \dot{w} A_{eff}$$

$$= 4.75 \left(\frac{1}{16}\right) \quad (1.21\ S_{WET} + 3.01\ D_{max}{}^2)$$

$$= .358\ S_{WET} + .894\ D_{max}{}^2$$

= where $\bar{W}$ = gas cell weight in lbs.

S_{WET} = hull surface area in yd^2

D_{max} = max hull diameter in feet

Boeing Helipsoid

The Helipsoid is assumed to be basically a rigid configuration with a structure similar to that of conventional airships. The structural beam spacing and the envelope seam density will be assumed similar to that of the conventional. Envelope material strengths for each velocity will be similar to those of the conventional airship, also.

at 50 knots $\overline{W}_H = .276\ S_{WET}$

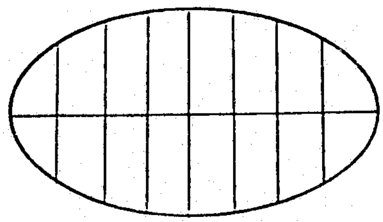
at 100 knots $\overline{W}_H = .276\ S_{WET}$

at 200 knots $\overline{W}_H = .331\ S_{WET}$

where $\overline{W}_H$ is in lbs.

S_{WET} is in yd^2

The gas cells for the Helipsoid will be assumed to fully fill the ship with one longitidunal and seven transverse bulkheads. See sketch.



In order to estimate the area of the bulkheads the following assumptions and/or approximations were made:

- bulkhead shapes are ellipses
- longitudinal bulkhead is through center of ship
- average transverse bulkhead is represented by major and minor diameters 90% of their maximum values.

$$A(\text{gas cells}) = S_{WET} + 2[\pi(L/2)(H/2)] + 14\ [\pi(.90S/2)(.90H/2)]$$

$$= S_{WET} + 1.571(L)(H) + 8.906(S)(H)$$

$$A(\text{gas cells}) = S_{WET} + 1.57(1.169S)(.292S)\left(\frac{1}{9}\right) + 8.906(S)(.292S)\ \frac{1}{9}$$

$$= S_{WET} + .060\ S^2 + .289\ S^2$$

$$= S_{WET} + .349\ S^2$$

where length, L, and height, H, are related to the span, S, by the following relationships:

$$L = 1.169S$$
$$H = .292S$$

and where S is in ft.

S_{WET} is in yd^2

A(gas cells) is in yd^2

Assuming again a 4% oversizing:

$$\bar{A}\ (\text{gas cells}) = 1.04\ A(\text{gas cells}) = 1.04\ S_{WET} + .363\ S^2$$

Again, the seam area of the gas cells and the supporting assembly will be assumed similar to that derived for the conventional rigid ships.

$$E_{ff}\ A(\text{gas cells}) = (1. + .058 + .10)\ \bar{A}(\text{gas cells})$$

$$= 1.158\ \bar{A}(\text{gas cells})$$

$$E_{ff}\ A(\text{gas cells}) = 1.204\ S_{WET} + .420\ S^2$$

Thus, the gas cell weight, assuming material similar to that of the rigids will be given by:

$$\overline{W}\ \text{gas cells} = \dot{w}\ (E_{ff}\ A(\text{gas cells}))$$

$$= 4.75\ \left(\frac{1}{16}\right)\ (1.204\ S_{WET} + .420\ S^2)$$

$$= .358\ S_{WET} + .125\ S^2$$

where $\overline{W}$ gas cells = gas cell weight in lbs.

S_{WET} = hull surface area in yd^2

S = maximum span in ft.

Aereon Dynairship

The Dynairship is assumed to be a rigid configuration with a structure similar to that of conventional airships. Structural beam spacing and envelope seam density will be assumed similar to that of the conventional rigid airship. Envelope material weights for each velocity will be similar to those of the conventional airship, also.

at 50 knots $\overline{W}_H = .276\ S_{WET}$

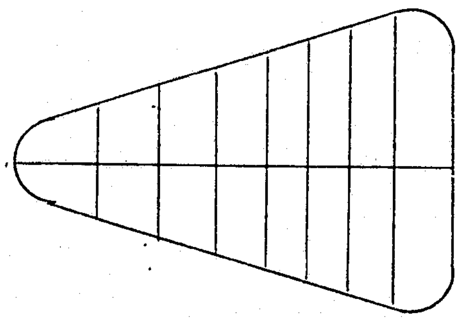
at 100 knots $\overline{W}_H = .276\ S_{WET}$

at 200 knots $\overline{W}_H = .331\ S_{WET}$

where $\overline{W}_H$ is in lbs.

S_{WET} is in yd^2

The gas cells for the Dynairship will be assumed to fully fill the ship with one longitudinal and seven transverse bulkheads. See sketch.



In order to estimate the area of the bulkheads, the following assumptions and/or approximations were made:

- bulkhead shapes are ellipses
- longitudinal bulkhead is through center of ship
- average transverse bulkhead is represented by a major diameter 75% of its maximum values and a minor diameter 90% of its maximum value.

$$A(\text{gas cells}) = S_{WET} + 2\,[\pi(L/2)(H/2)] + 14\,[\pi(.75S/2)(.90H/2)]$$

$$= S_{WET} + 1.57(L)(H) + 7.42\,(S)(H)$$

$$A \text{ gas cells} = S_{WET} + 1.57\,(1.328S)(.299\ S)\left(\frac{1}{9}\right) + 7.42(S)(.299\ S)\left(\frac{1}{9}\right)$$

$$= S_{WET} + .069\ S^2 + .247\ S^2$$

$$= S_{WET} + .316\ S^2$$

where length, L, and height, H, are related to the span, S, by the following relationships:

$$L = 1.328\ S$$

$$H = .299\ S$$

and where S is in feet

S_{WET} is in yd^2

A gas cell is in yd^2

Assuming again a 4% oversizing:

$$\bar{A}(\text{gas cells}) = 1.04\ A(\text{gas cells}) = 1.04\ S_{WET} + .329\ S^2$$

Again, the seam area of the gas cells and the supporting assembly will be assumed similar to that derived for the conventional rigid ships.

$$E_{ff}\ A(\text{gas cells}) = (1 + .058 + .10)\ \bar{A}(\text{gas cells})$$

$$= 1.158\ \bar{A}(\text{gas cells})$$

$$E_{ff}\ A(\text{gas cells}) = 1.204\ S_{WET} + .381\ S^2$$

Thus, the gas cell weight, assuming material similar to that of the rigids will be given by:

$$\bar{W} \text{ gas cells} = \dot{w}\,(E_{ff}\ A(\text{gas cells}))$$

$$= 4.75\left(\frac{1}{16}\right)(1.204\ S_{WET} + .381\ S^2)$$

$$= .357\ S_{WET} + .113\ S^2$$

where $\bar{W}$ gas cells = gas cell weight in lbs.

S_{WET} = hull surface area in yd^2

S = maximum span in ft.

8.0 COST

8.1 DESIGN COST

The soft goods design effort for a rigid LTA vehicle would consist of the following basic line tasks:

A. Material evaluations and selection

B. Loading analysis

C. Seaming development

D. Interface design

E. Gas Bag Design

F. Netting Design

G. Sub-scale Testing

H. Component Testing

In the case of non-rigid configuration, ballonet design and blower control system design would replace items E and F in the above list.

It is anticipated that a comprehensive program to accomplish the above tasks and result in manufacturing drawings for one particular LTA vehicle would require a two year effort and cost approximately \$2.6M. A projected cost breakdown follows:

Basic Materials and Process Research	\$ .45M
Structural and Configuration Design	1.50M
Testing	.50M
Documentation	.15M
Total	\$2.6M

If it should be desired to design a second vehicle similar in shape and configuration to the first it could easily be accomplished utilizing the first development work as a baseline. If the size change does not necessitate any major changes in material construction or interface configurations this second ship could probably be designed in about six to nine months and at a cost of about \$0.7 to \$1.0M.

8.2 PRODUCTION SET-UP

Soft goods components of large LTA system could be manufactured independently in sections or subassemblies. It is anticipated that conventional facilities could be utilized for all such subassembly fabrication.

The final assembly and erection of the LTA system would be accomplished in a large hanger or assembly building. It seems feasible at this time to consider using this same facility or a portion thereof for final soft goods assembly. In this manner only a final assembly operation would need to be established at the construction site. It is estimated that capital equipment expenditures for such a facility would be about $0.25M.

8.3 PRODUCTION COST

Non-rigids

Production costs for the soft goods components of a non-rigid LTA system is usually related to the hull volume. Past experience with aerodynamically shaped balloons have indicated definite trends for cost per cubic foot decreases as total volume increases.

Cost guidelines for non-rigid are shown in Figure 13.

Rigids

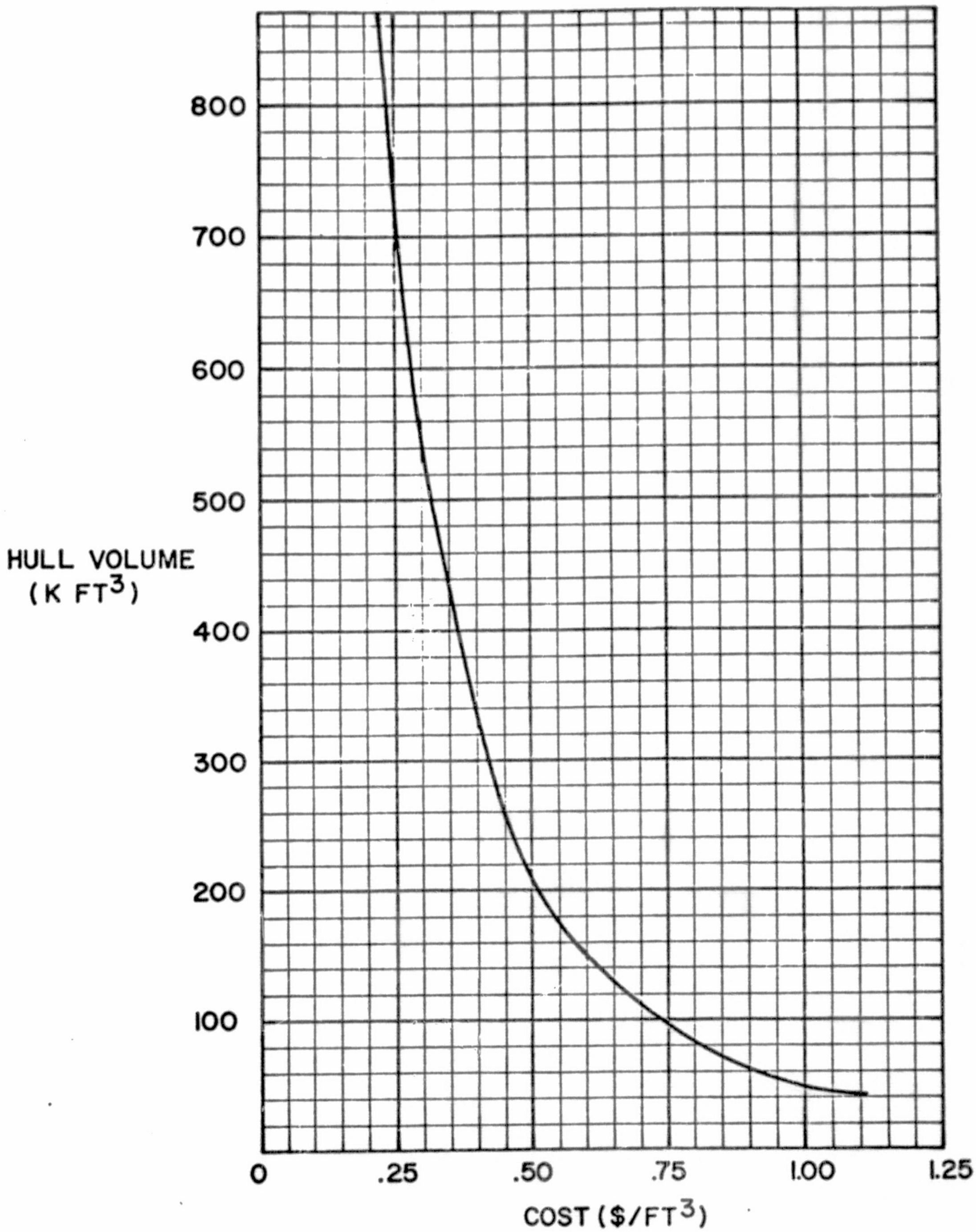
The soft goods components for the rigid airship will be fabricated in panels or gore subassemblies. Edge capture or attachment assemblies can be manufactured and integrated to the fabric panels at the subassembly stage. Final assembly at the construction or erection site can be accomplished by regular airship assembly personnel.

The gas bag assemblies can also be manufactured off site and brought to the assembly area for individual installation.

Cost estimates for a typical rigid airship envelope can best be expressed as a function of hull surface area. Gas bags are best related to surface area and maximum ship diameter. See Table 11 for projected soft goods cost estimates.

8.4 MAINTENANCE COST

It is anticipated that normal maintenance procedures such as inspection, washing, and local coating touch-up will cost on the order of 5% of the initial soft goods cost per year.



Conversion factors: $1K/Ft^3 = 28.32\ m^3$
$\$1.0/Ft^3 = \$35.31/m^3$

Figure 13

Major refurbishments which might be required after a ten year period could include recoating high wear areas on the external envelope, and selective replacement of internal gas cells. It is estimated that such repairs would cost on the order of 50% of the initial soft goods cost.

TABLE 11A

SOFT GOODS COST ESTIMATES (ENGLISH SYSTEM)

Airship	Envelope Costs (Dollars)	Gas Cell Costs (Dollars)	Total Costs (Dollars)
Conventional Rigid	$29.88\ S_{WET}$	$8.96\ S_{WET} + 22.28\ D_{max}^2$	$38.84\ S_{WET} + 22.28\ D_{max}^2$
Megalifter	$29.88\ S_{WET}$	$8.96\ S_{WET} + 22.28\ D_{max}^2$	$38.84\ S_{WET} + 22.28\ D_{max}^2$
Heli-Stat	$29.88\ S_{WET}$	$8.96\ S_{WET} + 22.28\ D_{max}^2$	$38.84\ S_{WET} + 22.28\ D_{max}^2$
Helipsoid	$29.88\ S_{WET}$	$8.92\ S_{WET} + 3.10\ S^2$	$38.80\ S_{WET} + 3.10\ S^2$
Dynairship	$29.88\ S_{WET}$	$8.92\ S_{WET} + 2.82\ S^2$	$38.80\ S_{WET} + 2.82\ S^2$

* Note: Material costs of \$10.00 per yd^2 for envelope and \$3.00/yd^2 for gas cells are assumed.

** Note: Gas cell netting for the rigid configuration could be made from 1/8 inch diameter Kevlar cord. It is estimated that a gas bag net of this material would cost on the order of \$2.40 per yd^2.

S_{WET}: hull surface area (yd^2)
D : maximum hull diameter (ft)
S : maximum hull width (ft)

TABLE 11B

SOFT GOODS COST ESTIMATES (INTERNATIONAL SYSTEM)

Airship	Envelope Costs (Dollars)	Gas Cell Costs (Dollars)	Total Costs (Dollars)
Conventional Rigid	$35.74\ S_{WET}$	$10.72\ S_{WET} + 239.29\ D_{max}^2$	$46.46\ S_{WET} + 239.29\ D_{max}^2$
Megalifter	$35.74\ S_{WET}$	$10.72\ S_{WET} + 239.29\ D_{max}^2$	$46.46\ S_{WET} + 239.29\ D_{max}^2$
Heli-Stat	$35.74\ S_{WET}$	$10.72\ S_{WET} + 239.29\ D_{max}^2$	$46.46\ S_{WET} + 239.29\ D_{max}^2$
Helipsoid	$35.74\ S_{WET}$	$10.67\ S_{WET} + 33.29\ S^2$	$46.41\ S_{WET} + 33.29\ S^2$
Dynairship	$35.74\ S_{WET}$	$10.67\ S_{WET} + 30.29\ S^2$	$46.41\ S_{WET} + 30.29\ S^2$

* Note: Material costs of $12.00 per m^2 for envelope and $3.60/$m^2$ for gas cells are assumed.

** Note: Gas cell netting for the rigid configuration could be made from 3.18 mm diameter Kevlar cord. It is estimated that a gas bag net of this material would cost on the order of $2.60 per m^2.

S_{WET}: hull surface area in (m^2)
D_{max}: maximum hull diameter in (m)
S : maximum hull width in (m)

9.0 MAINTENANCE

9.1 GENERAL INSPECTION

The envelope of an LTA vehicle should be essentially maintenance free during normal use for a period of at least ten years. Periodic inspection of the soft goods, especially in the area around load patches, structural mounting points and fabric seams should be conducted at regular intervals when the vehicle is being serviced. The frequency of such inspections will be determined by actual field experience with the vehicles.

9.2 COATING TOUCH-UP

Local coating refurbishment on the LTA envelope is possible if necessitated by abrasion or chafing of cables or lines which might come into contact with the skin. Such isolated repairs can be made by recoating the affected area in the field or applying scuff patches to the damaged area.

9.3 PUNCTURE REPAIR

A very serious problem anticipated with LTA vehicles is small punctures caused by vandalism, i.e., small arms fire from the ground especially when flying at low altitude during landing approach or take-off ascent. Another known hazard is contact with ground equipment or structures which might result in a torn envelope. Such holes and rips can easily be repaired when located by cementing a circular patch at least two inches larger than the hole on all sides. In the case of rigid airships it may be possible to make such repairs to the inside of the ship during flight.

9.4 REFURBISHMENTS

The external coatings utilized on a modern LTA vehicle will exhibit excellent resistance to environmental degradation. New materials such as urethane and tedlar films have excellent aging characteristics and accelerated aging test data has indicated a functional life on the order of ten to twenty years.

It is anticipated that the envelope of a modern LTA vehicle may require partial refurbishment as part of its regular maintenance program. The highly abused areas of the hull, namely the nose and upper quadrant may be recoated with additional new polymer at some interval during its useful life. It is expected that with such refurbishment about ten years after fabrication, the active life of an LTA envelope can be extended to twenty years.

This refurbishment can be accomplished piecemeal when the airship is moved between flights and need not cause any lost time due to extended layover or dismantling of components.

Internal gas bag replacement may be required during major refurbishment. Gas cell flex life and abrasion resistance will be the major properties governing life span.

REFERENCES

Alexandroff, Eugene E., (1974), Design, Development, and Testing of new Aerostat Material, Proceedings, Eighth AFCRL Scientific Balloon Symposium.

Burgess, C. P., (1927) Airship Design, Bureau of Aeronautics, United States Navy.

Keen, Larry B., (1974), Technology Update on Tethered Aerostat Materials Developments, Proceedings, Eighth AFCRL Scientific Balloon Symposium.

Myers, Philip F., (1968) Tethered Balloon Handbook, Goodyear Aerospace Corporation, AFCRL-69-0017.

Niccum, R. J., (1972) Comparison of Polyester, Film-Yarn Composite Balloon Materials Subjected to Shear and Biaxial Loading, G. T. Schjeldahl Company, NASA CR-2047.